CPE Comments and Topics

Justification for computers

IN the heart of many a brave chemical engineer the term computer often conjures up the terrifying spectre of knowledge unattainable. It is not surprising, as a result, that so much inherent resistance to computers is encountered from those technologists who have been unable or unwilling to come to terms with this useful tool. What are the justifications for using computers in process control and how are computers readily integrated into a process system? This is probably the commonest question asked, and our special feature this month on ' Computers for Process Control and Design ' examines this subject from various angles. The three articles comprising the feature state views both for and against extensive computer applications in the chemical industry.

Confusion is often encountered when trying to differentiate between automation systems (of which computers form a part) and mechanisation. An automation system is generally constructed from such basic items as measurement, communication, computation and control. The computer will enable such a system to exercise control over the basic variables; in addition it may also exercise logic and perform control functions according to predetermined rules. The term ' automation ' rather than ' mechanisation ' is justified for this system only because it can make logical decisions.

Undoubtedly, one of the major roles of the computer in chemical processing is to replace the human operator as controller of a process plant. Eventually, of course, the computer should perform such control tasks far more effectively than the human operator, who is limited in operating speed, storage capacity and by his inability to convert results rapidly and accurately into new demands for the controlled variables within the process.

Once the suitability and potential of a computer is appreciated, one is always confronted by the inability in the mind of the layman to differentiate between analogue and digital computers with reference to process control and design. Firstly, it must be appreciated that analogue computation, unlike digital computation, is fundamentally simple in concept. Electronic components simulate various parts of an equation. Voltages represent the variables and these voltages are added and subtracted at the same rate as the equation adds and subtracts the variables. Analogue computers thus operate in parallel, which means in principle that there is one component for each mathematical operation. Digital computers operate sequentially, using the same calculator for all operations.

Analogues, moreover, have a practical limit to the complexity of the problems they can handle because they operate in parallel. The digital computer, on the other hand, needs mostly expanded memory to handle bigger problems since it uses the same calculators for all operations. For practical purposes, the analogue computer is most suitable for systems involving simultaneous differential equations, either linear or non-linear, with constant or varying coefficients as, for example, control system design, applied research and processing design. Digital computers, on the other hand, are ideal for matrix calculation, linear programming, statistical correlations and processing large masses of data as in inventory control.

Unlike the British chemical industry, which is still rather conservative in this regard, American chemical industry is investing increasing sums in computer systems. Sales of computers to the American chemical industry were recorded as $1.5 million in 1960, and it is expected that by 1965 this should have reached $10 to $20 million!

Perhaps this trend is due to the greater spirit of adventure (and possibly greater financial resources) which American industry seems to have. It is by no means certain that computer systems are quite as successful and money-saving as most of their staunch protagonists would have us believe—indeed there seems no sure way of finding out, short of actually buying and installing one!

Phthalic anhydride boom

THE news that Grange Chemicals are going to build a 15,000-tons-p.a. phthalic anhydride plant has once more drawn attention to the boom in this organic chemical. The biggest use for phthalic anhydride nowadays is in alkyd resins which go into surface coatings. Second biggest use is in phthalate ester plasticisers (most notably dioctyl phthalate), which are of great importance in PVC compounding. A third application is in production of polyesters for glass-reinforced plastics. Other subsidiary uses are in dyes, pigments and pharmaceuticals.

Traditional raw material for phthalic anhydride has always been naphthalene, which is obtained as by-product from coke ovens in the steel industry. However, the rapid expansion of the chemical industry during the last ten years has been accompanied by a slight decline in steel production; hence supplies of naphthalene have become increasingly scarce during the 1950s, culminating in acute shortages in 1960. This state of affairs has turned attention to alternative sources of raw materials such as petroleum naphthalene and ortho-xylene. In the U.S. only one company so far is using ortho-xylene as a raw material, California Chemical Co. (who, incidentally, own a third share in Grange Chemicals and are building an ortho-xylene

plant at the B.P. Isle of Grain refinery). The reluctance of American producers to switch from naphthalene to ortho-xylene is due to the fact that naphthalene from petroleum is more likely to be economic in the U.S. than in Europe because very large platinum reforming systems and abundant sources of cheap hydrogen in most American refineries have reduced production costs of naphthalene.

Eventually, of course, the suitability of either petroleum, naphthalene or ortho-xylene as raw material for phthalic anhydride will be determined firstly by the cost per pound and secondly by the percentage conversion to phthalic anhydride that can be obtained in the most efficient plant. At present it would seem that ortho-xylene is leading on those two counts—but only by a very small margin.

Spray refining

THE British Iron and Steel Research Association, with a membership of 442, is one of the largest research associations in this country. Its comparatively high income of £945,599 in 1960 ensures that even more money is being devoted to fundamental research in iron and steel making. The B.I.S.R.A. annual report for 1960 discusses the findings of a working group which was set up to study the optimum usage of oxygen in open-hearth furnaces.

It was found that the use of oxygen to enrich the combustion air for melting has cut fuel consumption by as much as 14% and reduced tap-to-tap times by up to 20% in cold-charged furnaces. In addition, oxygen lancing during the refining period has reduced the fuel consumption by about 65%, besides reducing refining time. Further work is currently being planned to determine the conditions for the optimum usage of oxygen. Aspects that must be considered in this connection include the influence of gas velocity, the design of the injection device and its distance from the slag/metal surface, and the influence of the metal composition on the extent of foaming and splashing.

Spray refining is the atomisation of a stream of molten blast furnace metal by a suitable arrangement of oxygen jets to refine the metal. Following the promising results obtained from laboratory experiments on a 10-cwt. scale, a pilot plant for the pretreatment of hot metal by spray refining was designed and erected by B.I.S.R.A. Experiments are being carried out using 16-ton batches of hot metal which are treated at rates of up to 2 tons/min. with oxygen flow rates ranging from 250 to 600 cu.ft./min. At low metal flow rates the metal can be adequately atomised and oxygen used very efficiently. Experiments are now in progress to determine the form of atomising device that will ensure adequate utilisation of oxygen at high metal flow rates so as to give any desired degree of refining. It is felt that, when spray refining has been fully developed as a technique, it will prove to be a simple and inexpensive method for pretreating iron to make it suitable for finishing to steel in any type of furnace or converter.

Dutch nuclear activities

NETHERLANDS, small in size and population, is engaging in quite comprehensive nuclear activities. The establishment in 1951 of Norwegian-Dutch co-operation may be regarded as the origin of the Dutch nuclear industry. The Reactor Centre of the Netherlands (R.C.N.) was founded in July 1955 by four separate groups, each of which is concerned with one aspect of nuclear energy. These are the Dutch Government, the Foundation for Fundamental Research on Matter (F.O.M.), the Testing of Electrical Materials Co. (KEMA) and a large number of industrial companies. In north-west Holland, near the village of Petten, a research centre has been rapidly developing. Its purpose is to co-ordinate scientific and industrial interests in the nuclear field in Holland.

At present a 20-MW materials testing reactor is under construction and will probably become critical towards the autumn of this year. This high-flux reactor is a pool type with 90% enriched uranium which will produce a maximum thermal flux of 2.4 $\times 10^{14}$ neutrons per cm.$^{-2}$ sec.$^{-1}$ A 10-kW low-flux reactor was completed last year and became critical in September 1960. This is of the *Argonaut* type, also using 90% enriched uranium and producing a maximum thermal flux of 1.5 $\times$ 10^{11} neutrons per cm.$^{-2}$ sec.$^{-1}$.

A large number of Dutch companies are already engaged on nuclear projects. Six of these companies have formed a consortium, known as N.V. Neratoom, with the purpose of co-ordinating the manufacture and erection of land-based power reactors. Development of a nuclear power programme has gone at a slower rate than anticipated because nuclear energy as a basis for the commercial production of electricity still appears to be non-competitive when compared with conventional power generation.

'New look' in technological education

THE scheme for creating Colleges of Advanced Technology was initiated by the government in 1953 in order to overcome the chronic and ever-worsening shortage of scientists and engineers. The scheme proposed at that time was quite novel—in many ways even revolutionary. The course of studies would consist of alternating periods of six months college studies followed by six months industrial training. At the termination of this ' sandwich ' course the student would be awarded a diploma in technology, equivalent in standing and prestige to a degree. It was hoped that this kind of training would turn out technologists with an inbred appreciation for the industrial needs—having a more practical approach towards day-to-day problems than university graduates.

It is, of course, much too early to judge the success of this scheme—only one harvest of students have graduated to date. Nevertheless, it is astounding to note that already, the nine existing Colleges of Advanced Technology have been accepted without inbred prejudice by the large number of students. A

recent visit which we paid to the Bradford Institute of Technology brought us into contact, for the first time, with the enthusiasm which this 'new look' in technological education is generating amongst students and staff.

The Department of Chemical Engineering at Bradford, although already in existence (on a modest scale) since 1923, has been considerably expanded since 1957. The acting head, Mr. C. W. Page, has gathered around him a young, enthusiastic team of lecturers all with considerable industrial experience in the chemical industry. The staff is responsible for placing students in industrial positions for every six months of the year. Many of these positions are abroad and hence a considerable amount of travelling is undertaken by the staff in order to visit every student at least once for tutorial guidance. As a result, the students' outlook is widened and they become reasonably conversant in at least one foreign tongue (no mean achievement for Englishmen!). Already the number of applications for places in the course is growing; students are beginning to come from many parts of the country and the Commonwealth. This is perhaps an early and favourable sign of the benefits that C.A.T.'s may bestow on the educational system.

Fluorine corrosion

FLUORINE undoubtedly is the most active element known. It is liquid between −306° to −353°F. at atmospheric pressure (this is just below the temperature of liquid oxygen). How can liquid fluorine best be stored without even the slightest loss to atmosphere? J. D. Jackson discussed this topic in a recent paper in *Chemical Engineering Progress*, 1961, **57**, 61. He suggested that fluorine losses to atmosphere are best prevented by using liquid nitrogen (boiling point, −320°F) as an inert coolant to maintain the fluorine in a liquid state.

The reason why fluorine is readily contained in a liquid state is due to the formation of a non-volatile adherent fluoride film. The temperature at which a material shows satisfactory resistance to fluorine is probably related to the sublimation or melting points of the fluorine compound formed. For example, nickel metal is resistant to fluorine up to about 1,200°F. because the nickel fluoride film on the surface is still adherent, while aluminium and copper are good up to 700°F., steels up to 600°F., titanium up to 300°F. and tantalum only up to room temperature.

However, alloys containing silicon, molybdenum, columbium or carbon may be subject to pitting attack resulting from the high vapour pressure of their fluorides. Melting points of fluoride films, according to Jackson, are important only when liquid fluorine is undergoing cycling up to room temperature or above. Of more importance would be the solubility of fluorides in liquid fluorine, but little information is available on this. It must be remembered that the corrosion resistance to liquid fluorine is strictly dependent on the cleanliness of the metal surface. Hence it is always advisable, after removing traces of organic material from metal, to use a passivation treatment—flushing the metal with fluorine gas diluted with an inert gas.

Another important factor is the purity of the fluorine. Water, for example, is an impurity often present in liquid fluorine and its presence increases the corrosive attack of liquid fluorine on metals due to the formation of hydrogen fluoride. Such attack is noted even when the water content is as low as 0.2%.

Hydrogenation platinum catalysts

ALL six metals of the platinum group—platinum, palladium, rhodium, ruthenium, osmium and irridium—exhibit considerable catalytic activity, but only the first four are nowadays used to promote hydrogenation reactions. This was pointed out by P. N. Rylander in a recent article in Engelhard Industries' Technical Bulletin. In actual fact, platinum metals are often so active that even an improper choice of catalyst frequently gives satisfactory results in the laboratory. Although in industrial practice it is difficult to generalise about the optimum use of platinum catalysts, there are certain criteria that must be applied in selecting a particular catalyst for a reaction.

Rylander discusses several such criteria which have all been derived from practical experience in this field. In order to show catalytic activity it is necessary that platinum catalysts are supported. Thus, on a weight metal basis, a properly supported catalyst shows higher activity and greater resistance to poisoning than a non-supported catalyst. The activity of a catalyst depends on the solvent used. Although many solvents have been used in low-pressure hydrogenation, it is best to try out initially any solvents that can be used; ethyl alcohol or acetic acid, for example, have frequently proved to be good solvents. Although most hydrogenations with platinum catalysts can be carried out at atmospheric pressure and temperature, it is often desirable to work at elevated temperatures and pressures.

Activity, selectivity and catalyst life are all affected by agitation. Because many platinum metal reductions are diffusion controlled, the reaction rate is limited solely by the rate at which hydrogen can be supplied to the catalyst surface, hence vigorous agitation is essential. From limited data available it appears that increasing agitation tends to increase catalyst life. It was found in several cases that on hydrogen-deficient catalysts half-hydrogenated products condense and polymerise to give products that are catalyst inhibitors. When hydrogenation deficiency is severe, these materials form in such amounts that they can actually be scraped off the catalysts. However, with adequate agitation this does not occur. Although platinum catalysts are non-pyrophoric, they do catalyse the oxidation of organic compounds and great care must be exercised when catalysts are brought into contact with alcohols or combustible vapours. Thus it is often routine practice when handling alcohols to dry both the catalyst and alcohol in dry ice before mixing. Especially active catalysts must be both cooled and blanketed with nitrogen.

North African oil resources

MUCH has been forecast about the extensive oil deposits in North Africa, but it must not be forgotten that they are still in their very early stage of development. Last year's output in Algeria, for example, was closely equivalent to that of Qatar which is the fifth largest oil producer in the Middle East.

An ever-increasing number of companies of many nationalities have been securing a stake in the future of the Sahara by taking out concessions, separate interests frequently amalgamating for this purpose. Quite prominent among these are British companies acting in association with French interests. One area in which they possess a considerable share is the Edjele oilfield and a second district in which there are British interests is the Tabardine gasfield, which possesses considerable resources of natural gas, although its development is likely to be retarded due to its considerable distance from the sea. To convey the gas to the coast, which is an essential prerequisite to any large-scale marketing of North African natural gas, it would be necessary to construct a pipeline nearly 1,000 miles in length. Naturally only very substantial reserves of gas could justify the heavy capital outlay for such a project. There are also Dutch, American, Italian and Spanish companies who have interests in these oil and gas fields.

Much more accessible natural gas resources are available at Hassi R'Mel now being connected by pipeline to the coast. This is reputed to be one of the most prolific gasfields in the world—capable of supplying the natural gas requirements of Western Europe for a long time to come.

U.S. approach to nuclear power

WHEN assessing the value of American contributions to the nuclear power programme, it must be remembered that the official U.S. programme is not aimed primarily at producing kilowatts. It is rather designed to develop technical information for the construction of commercial plants by the American electric utility industry.

At present, privately owned U.S. electric utility companies are either building, planning or negotiating for 17 nuclear power plants. Of these, five are already in operation: Dresden (BWR), Yankee (PWR), Shippingport (PWR), Vallecitos (BWR) and Santa Susana (sodium-graphite). Seven are under construction: Indian Point (PWR), Pathfinder (BWR), Humboldt Bay (BWR), Enrico Fermi (sodium cooled), Parr Shoals (gas cooled), Saxton (PWR) and Big Rock Point (BWR). Two are under design (ECNG-FWCNG) and Peach Bottom, one is under negotiation, Southern California Edison, and two are being planned, New England Electric System and Pacific Gas & Electric.

In those projects at present carried out, seven different reactor concepts have been used. These are the pressurised water-cooled and moderated, boiling water-cooled and moderated, pressurised water-cooled with heavy-water moderator, gas-cooled with heavy-water moderator, sodium-cooled with graphite moderator, sodium-cooled fast breeder and high-temperature gas-cooled.

The fact that more than half the current U.S. nuclear power development projects use water as a primary coolant is due partly to its ready availability and partly due to the fact that the selection of water represents a logical extension of American advanced steam generation technology. Although, at first, nuclear reactor experts believed that it would be impossible to permit water to boil in the reactor vessel, scientists from Argonne National Laboratory (who had recommended the pressurised system) began to question the validity of this. Their work led to the experimental boiling-water reactor. Present indications are that the pressurised and boiling systems will be brought together with ' local boiling ' to generate steam in pressure tubes instead of in a large vessel. The system, of course, requires enriched uranium, not natural uranium. An advanced reactor of this type is under design by the Carolinas-Virginia group, using heavy water as both coolant and moderator

German without tears

FRANKFURT, as our readers will have noted, has blossomed forth as one of Europe's most important exhibition centres. This fact is not wholeheartedly appreciated by most Frankfurters who still (unreasonably) consider it tiresome to get used to a population increase of 25% every few months!

An unsuspecting (and monoglot) Englishman, descending upon Frankfurt for a trade exhibition, would be fully justified therefore in assuming, without further evidence, that the native Frankfurters are reasonably conversant with English (perhaps not of the Oxford variety but most definitely as spoken in Manhattan). But far from it. Such assumptions may be valid in sunny Sicily or polyglot Istanbul, but in Western Germany, however, the *lingua franca* is still (surprisingly) German. Our English visitor, therefore, will soon attempt after his arrival to harangue local officials in French—which he learned about 40 years ago. Alas, he is informed (in sign language) that nobody understands Chinese and, reluctantly, he is forced to buy a treatise, ' German Without Tears '.

Having mastered the first half-dozen pages of this primer he once again ventures forth to converse with the natives; but there is more disappointment. Again he fails to make himself understood, even at the lowest levels. In desperation he is prepared to call in the United Nations. Little does he realise, however, that, even if a battalion of German interpreters were seconded by the U.N. to aid distressed British visitors, there would still be an insurmountable snag. The native Hessian dialect, as spoken in Frankfurt, is quite incomprehensible to Germans outside Frankfurt —hence our Englishman would be in good company. Perhaps he should instead brush up his French for the next trade fair in Nice?

Profitability of Computers in Process Development and Operation

By A. J. Young,* B.A., B.Sc.

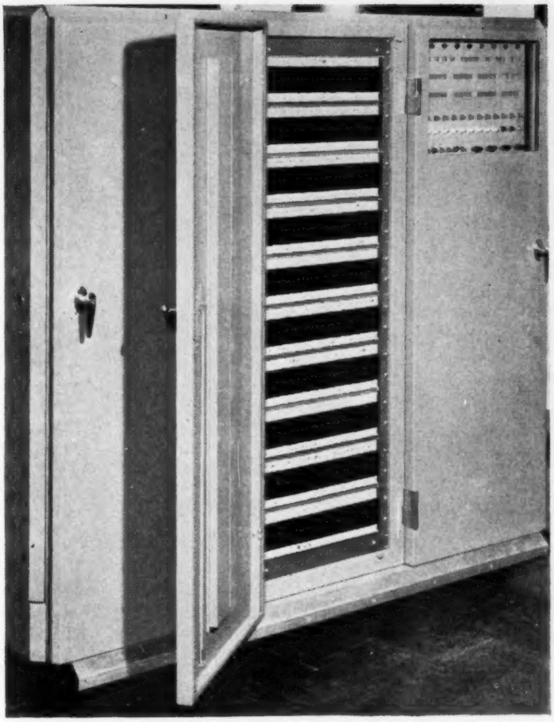

Fig. 1. Main unit of the Ferranti 'Argus' process control computer

Despite the attention which has been focused on the application of computers to process control, there is so far little evidence to substantiate their profitability in this sphere. This article shows why the use of computers in the chemical industry is limited by the present shortage of mathematicians. Discussing the suitability of computing effort in the various departments of the process industry, it is shown that the most profitable area to apply the computer is likely to remain in the research and development stage of a new project.

A GREAT deal of attention has been focused on computers during the last few years. Very many publications have been devoted to describing their method of operation, their prodigious capacity for rapid computation and their potential value in all parts of industry. A considerable number and variety of applications have been described and most of these have been claimed to be profitable. In some instances, but not in very many, the extent of the profit derived has been stated and substantiated. But the type of application which, it would seem, has been the subject of most attention and which has apparently captured the imagination of the majority of technologists, is the use of the computer to operate on the plant as part of the process control system. This is also the type of application for which perhaps the least evidence has been produced to substantiate its profitability.

The purpose of the following remarks is to redress the balance, because it is very important that the severely-limited effort available in the process industries for development of computer techniques and applications should be deployed to best advantage. It should, however, be stressed at the outset that it is clearly important to develop every type of application and that the use of computers for direct control of processes is certainly not an exception to this.

Shortage of mathematicians

The introduction of computers into industry has had the effect of making mathematics a much more valuable aid in the solution of all kinds of problems. Consequently, the demand for mathematicians has outstripped the supply and some years must elapse before the universities and colleges of technology can produce mathematicians at a sufficiently high rate to satisfy industrial needs.

The mathematician has three main responsibilities in the process industries, namely to develop mathematical techniques, to apply these techniques to the solution of industrial problems and, thirdly, to assist his technologist colleagues in the mathematical treatment of their everyday problems.

While the shortage of mathematicians persists, it will be necessary to ensure that their effort is distributed to best advantage among these three respon-

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sibilities. The problem is acute because the majority of technologists in industry are not in the habit of bringing a mathematical approach to bear on their problems and the third responsibility of the mathematician is therefore very onerous.

It is important to emphasise this fact, because it is not generally appreciated that a great deal of the mathematician's time is at present being occupied in formulating problems for technologists, who must as rapidly as possible be put into a position to do this for themselves. Most chemists and engineers find no difficulty in learning to programme their problems for solution by a computer, once these have been put into an appropriate mathematical form.

Universities and colleges of technology are aware of the importance of providing their scientists and engineers with the necessary mathematical training to do this. The mathematicians in industry would agree wholeheartedly with the Minister for Science when he said recently that the shortage of mathematicians in industry would be considerably ameliorated by the more appropriate mathematical grounding now being provided for the technologist. This will free the mathematician to work on the improvement of his techniques.

The technologist also gains from using computers himself, because the computer imposes a rigid discipline on its user in his approach to a problem. The computer can only carry out the instructions written into the programme by the user, who is forced to recognise the limitations imposed on the usefulness of the solution by inadequacies in his description of the problem or in his data. The value of this discipline is emphasised in the following quotation from a recent publication:[1]

> 'It is clear . . . that the greatest immediate benefit (of using computers) arises from the necessity of formulating the problem concisely, stating the known (or assumed to be known) information as accurately as possible—and the initiation of work to obtain more and more accurate information. The demand for a logical approach improves both the thinking and the quality of data put into solution of the problem. Then, when all the real work of intellectual content has been done, the computer uses it effectively by presenting calculated results rapidly. Computers do not think, but they make human beings think very much more—and then calculate for them.'

Current priorities

It would seem to be abundantly clear that first priority should be given to putting many more technologists into the position of being able to formulate their everyday problems in appropriate mathematical form and to programme these problems for solution by computer.

Computer designers have made a great contribution to this objective by incorporating facilities in their machines to facilitate programming. For some time, considerable mathematical effort will have to be devoted to teaching the procedure to technologists generally and to assisting them to formulate their problems.

Some companies have already made very considerable progress in this direction. For example, 500 chemists and engineers in I.C.I. have been taught to programme the Ferranti *Mercury* computer in 'Autocode'.

Meanwhile, as long as a limitation is imposed by the mathematical effort available, it is necessary for industry to decide in which fields of activity the computer can be expected to produce the greatest profit. The choice must, of course, depend on the circumstances at any time in any one organisation, but the following considerations lead to an order of priorities which have been confirmed by available experience.

Clearly, the most important decisions taken in any organisation are those which determine its general policy and the pattern and balance of its activities. The use of computers in helping to make these decisions has not been developed to any considerable extent and the problems to be solved are essentially concerned with management technique rather than computing technique. The computer can handle vast quantities of data, when they are available, about markets and sales, the profitability of research, process development, process output, efficiency and yield, competing products, various types of advertisement, quality of technical and commercial staff and so on. But until the relationships between all these factors which determine policy are known, management cannot take advantage of the computer's ability to compute the results of their interplay.

Thus it is not yet possible, for example, to compute the most profitable way to distribute the organisation's expenditure between research, development, production, etc.—although this would be the first thing to enlist the aid of a computer to do, if it *were* possible.

At present the most useful step is to use the computer to assist in assembling and ordering the data which are available, and to analyse them with the object of determining the relationships between the factors involved in management decisions.

The following discussion applies to an organisation in which there is a proper attempt to get the best balance of effort among the activities competing for financial support. Clearly, it could not be argued that computers would be of first importance in research, in an organisation in which research was badly neglected; or that on-line computers would improve process operation in a firm which operated simple processes long since optimised over years of experience.

In the process industries, the technical functions of the various departments are (broadly), research, process development (including, for convenience, project evaluation), flowsheeting, plant engineering design and layout, construction, process start-up and operation, and process investigation and improvement. Economic considerations arise at each stage of the development of a new process from research to start-up and subsequently during operation, and they have to be taken into account in spite of their inherent uncertainties.

The field of application is therefore very wide, but it can be covered by considering two cases: the operating process and the process to be developed from the early research stage.

Computers can be used in three ways to help to improve the profitability of a process already in operation. First, they can be used by a process investigation team to assist in the analysis of process data with the purpose of obtaining more information about the behaviour of the process in operating conditions. Secondly, they can be used as part of the plant instrumentation to receive process data directly from the plant measuring instruments, or sometimes through the medium of the process operator, and to compute energy and matter balances, plant efficiencies and so on, for the information and guidance of the works manager. They can also be used as part of the automatic control system of the plant or, in current terminology, for 'on-line' computer control.

The second application, in which a computer is used for straightforward computations on process data, need not be considered in this context, because it presents no development problem for the mathematician, although there may be considerable

difficulties in perfecting the measuring equipment and linkage between it and the computer. If the function of such a computer is more sophisticated (as, for example, if it is used to provide a statistical model of the process), then its use is similar to that of a computer used in process investigation —except that in this instance it is connected directly to the plant.

The use of the computer during a process investigation can either be to carry out an analysis on the process measurements, with the object of building up a statistical model of the process or, more simply, to correlate changes in the various plant conditions, or alternatively to check a mathematical model of the process against the measured behaviour of the process itself. In either case the object of the investigation is to discover more about the behaviour of the process and for most processes in operation at the present time there remains a great deal to be discovered. This is, however, only because the chemists and chemical engineers who produced the flowsheet and designed the plant did not have access to a computer to assist them.

No one would, however, hold the view that it is preferable to build the plant first and then carry out a process investigation to improve its profitability, rather than to carry out the investigation before the flowsheet is drawn up—always provided that the theoretical and experimental data necessary can be obtained in time to permit this. There can be no doubt that processes and plant designed in the future, after the reaction kinetics and process mechanism have been thoroughly investigated and elucidated, will prove far less rewarding subjects for subsequent investigation after they have been started up.

There will, of course, always be disparities between prediction and full-scale process behaviour due to one cause or another, and it will always be valuable to improve knowledge of the behaviour of the process in full-scale operation by taking careful and comprehensive measurements and by using them to improve the chemists' mathematical model of the process. It will, however, be clear that the most important time for using the computer in this way is at a very much earlier stage in the life-cycle of the process, namely in the early research and development stages.

The third use of the computer—namely, for process control—must also be considered. Again the question is rather different when asked about an existing process than when asked about a process to be designed. It has already been pointed out that a considerable amount remains to be learnt about the majority of existing processes, and it may well be that a process investigation will reveal the need for a computer to control the process continuously. This might be for one of two reasons. In the first place, the process conditions for one reason or another may be so variable, from day to day, that a computer offers the only practical possibility of handling the complex relationship between the variables and of computing the best set of conditions in given circumstances. These relationships must, of course, be available to the computer; they must either be discovered previously and written into the computer programme, or they must be discovered during process operation by the computer itself. The second reason for using a computer is quite simply that it might be cheaper to install it in place of the usual controllers which control individual conditions. Such an installation is, in fact, being made in one of the I.C.I. Divisions at the present time, using an *Argus* process control computer instead of about 100 singleloop controllers. (Fig. 1 shows the Ferranti *Argus* computer.)

Table 1

Application	Order of profitability		
	New processes		*Operating processes*
(1) Research	A		
(2) Project appraisal including (*a*) relationship with other processes (*b*) 'risk' calculation Process development	A		
(3) Flowsheet, including utilisation of sources of raw materials	A⁻	*Decreasing profitability* ↓	
(4) Plant design, including control system (with on-line computer if method of operation makes it advantageous)	B+		
(5) Start up and operation	B to C		↑ C to B
(6) Process investigation and development, including new research initiated	C		B+ to B

NOTE.—The assessment of relative profitabilities of applying computers at the various stages is, of course, only intended to represent the general pattern, but it does indicate on which type of application effort should be concentrated.

The fact that most reports of on-line computer installations have emphasised that the profit obtained from the process investigation preceding the installation of the computer have considerably exceeded the profits to be expected from the operation of the computer itself, should not be allowed to detract from the very great potential of the computer as a means of increasing the profitability of the chemical processes. It has been explained already that careful investigation of most processes at the present time must lead to considerable profits and this implies that such reports were only to be expected. On the other hand, it is by no means clear that the installations already made are using computers to best advantage on the processes they control, nor indeed that the processes selected for these installations are ones which would naturally provide the most favourable conditions for obtaining increased profitability by using an 'on-line' computer.

It can, however, be said that the on-line computer as well as the process investigation cannot in the nature of things be expected to produce as profitable a result as a better design of process and plant in the first place. Consideration of the way in which computers can be used throughout the life cycle of a process, starting from the early research stage, will put the value of the process investigation on the operating plant and of the on-line computer in their proper perspective —without in the least detracting from their considerable potential.

Projected process

Experience has shown how very valuable the computer is in helping the chemist to study the kinetics of reactions and the mechanism of processes in the research stage of a new project. Before computers became available, the chemist was, of course, equally well able to write down the mathematical equations describing his hypothesis with regard to the reaction. His difficulty was that these equations, which are now so often referred to as the mathematical model of the reaction, generally proved extremely tedious to solve and in many cases proved to be insoluble by analytical

methods. As already stated, it is quite obvious that the chemist could not afford the time to try to test his mathematical model of the reaction against his experimental results. He would have been involved in a lifelong series of calculations of the responses of his model to various conditions corresponding to those of his experiments and, unless he happened to be correct in his first hypothesis, he would have had to continually change his model and complete his calculations in order to check against experiment. The chemist was, in fact, well advised in those days to plan his experimental programme in order to make the comparatively few calculations he had time to do as simple as possible. Nowadays the very reverse is true. Calculations can be done at great speed by the computer and the research programme can be planned to reduce experiments to a minimum. This is very important, because it saves time.

Basis for development

Even more important, the research chemist will in future be able to hand on to those responsible for subsequent development a very much more complete knowledge of the reaction. This will allow the effect of changing operating conditions to be predicted with considerable accuracy. It will therefore be possible to work out the most economic method of operating the process, taking into account the limitations imposed by plant equipment and materials, sources of supply of basic materials and so on. Moreover, at the development stage or even earlier, the profitability of the project must be assessed and this in turn means that the market demand must be forecast and all kinds of contingencies must be taken into account and the optimal throughput must be assessed. Clearly, with such a complex situation to deal with, the computer must be a most useful tool at the development stage. A thorough discussion of all the problems involved would run to a considerable length, but it is sufficient to have indicated how useful the computer is at the development stage and to point out that among other applications it will inevitably be used a great deal to determine the best methods of operation, best production rates of various products, choice of materials and so on, and all those studies which come under the general heading of 'operational research'.

When the research and development of a project has been taken sufficiently far to arrive at the flowsheet stage, a computer can again be employed very profitably. So far there have been no reports of work in this country of the ambitious character which is said to be carried out successfully in the U.S.A. by some of the large oil and chemical companies. Work on optimisation of flowsheets has, however, been proceeding in a modest way and foundations for more ambitious programmes to assist in the optimisation of flowsheets are under way. When the flowsheet is being drawn up, the method of control of the process will be decided and the function of the control system will be specified. This specification will determine whether or not the desired control quality can be achieved in all operating conditions envisaged without bringing in an on-line computer, or whether it would be profitable, in view of the nature of the reaction and what is already known about it, to employ an on-line computer as part of the control system. The answer to this question in the future must to a considerable extent depend on the success of developing on-line computer control systems which dispense with the normal single-point controllers at present in use. If this is successfully achieved then, as already stated, the cost of including a computer may be a negligible increase over orthodox control equipment.

The plant design stage and the flowsheet stage must to some extent overlap because the method of operation selected and the type of plant equipment used must depend on capital and operating costs and on the performance of the various pieces of equipment. In making the final choice, compromise is necessary and, in the past, a great deal has been left to the judgment of the individual chemist and engineer, who have in fact not been able to consider more than a few possibilities. Even these few possibilities have not been considered sufficiently quantitatively because of the difficulty of finding time to carry out the necessary calculations. Now, however, standard practices have been developed for dealing with the many design problems that occur. For many routine calculations it is only necessary for the designer to fill up a standard data form and send it to a computing service for the required answers to be produced. Again, therefore, the computer is of great importance not only in speeding up the work of a design department, but also in permitting it to consider as many alternative proposals as it wishes. The result must be to increase the economy of plant design and the efficiency with which the plant operates when it is built. Nevertheless, the whole profitability of the project must rest on the chemistry of the process, and however profitable it may be to use computers to assist designers to produce the most economic plant and to assist in drawing up at the previous stage the most efficient flowsheet, the most profitable application of all is to be expected at the research stage.

There is no need to mention the on-line computer at the engineering design stage because the designer will make provision for the type of control system which it has been decided at the flowsheet stage will be economic. But, before leaving this subject, it is desirable to point out that, by concentrating computing effort on the research stage, the comprehensive knowledge of the reaction which will result from this should present a much more favourable situation at the flowsheet stage for consideration of the control system. If the relationship between the operating conditions and the efficiency of the process can be predicted with sufficient certainty, then it is a straightforward matter to make a choice of control system. If it so happens that a computer is included, then it will have a very sound basis of information upon which to operate and it can be arranged to refine this information and keep it up to date automatically.

Conclusion

Everything that has been stated points to the conclusion that the most profitable area in which to apply the computer is, and is likely to remain, in the research and development of a new project. It is suggested that the order of profitability, and therefore of the priority to be given for computer applications, is as indicated in Table 1.

The merits of devoting effort to process investigation work on operating plants compared with the merits of putting the same effort into research on new processes, can only be decided against the background of an organisation's policy and resources and in individual cases. In general, however, it would seem that research should be given every possible assistance that computing techniques can give, even if this means reducing the effort that can be devoted to development and application of computers and computing technique for application at any later stage in the life cycle of a process.

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[1] *Ind. Chem.*, 1961, **31**, 237.

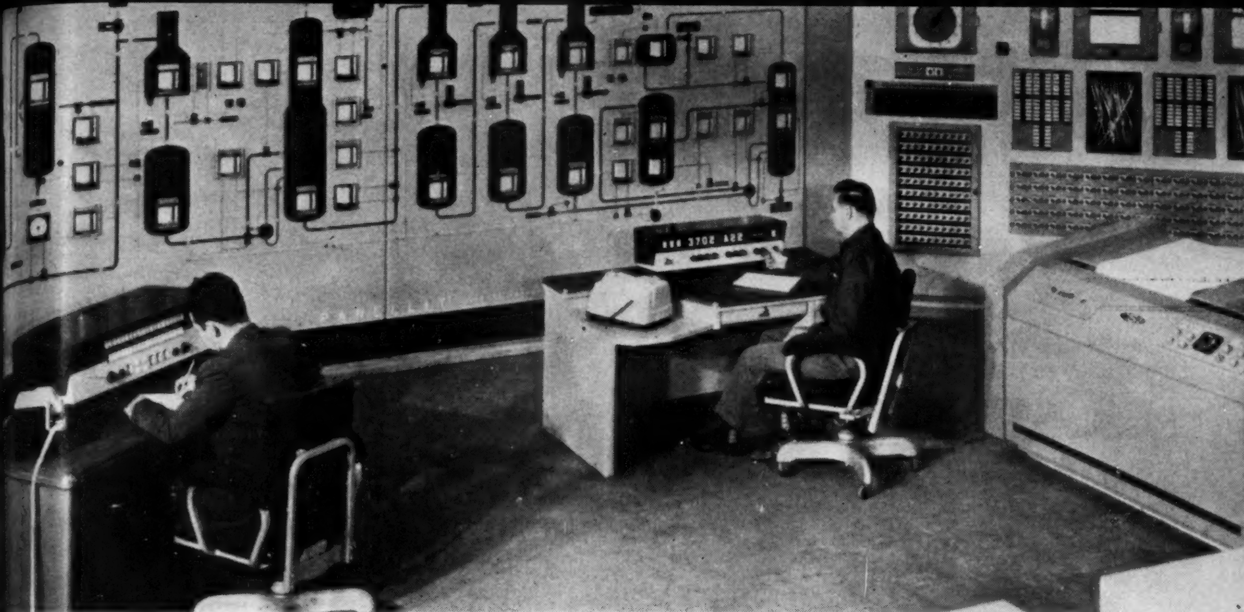


Fig. 8. Computer-controlled system installed in a chemical works [Courtesy: Elliott Bros. (London) Ltd.

Applications of Computers to Process Control

Part 1

By J. F. Roth,* B.Sc., A.M.I.E.E.

The complexity of modern chemical plants makes their monitoring and control increasingly difficult. This article illustrates how considerable improvements in efficiency and productivity can result from the application of either fixed-programme or computer-controlled systems to process control. A detailed description of data processing systems is given and, by combining these with digital computers, various computer-controlled systems are obtained. These may or may not be combined with fixed-programme systems to give substantial savings in process costs.

WITH the ever-increasing complexity of modern plants and processes, the need for improved methods of monitoring and controlling them is becoming more essential. In the not-so-distant past, plant instrumentation was of a most elementary kind. The control panel would have a few rudimentary meters, but the overall control of the process or machine was in the hands of someone who employed rather more witchcraft than science. The modern control room presents a very different picture. A vast array of meters, indicators and displays confront the plant operator. So much information is presented which, coupled with the fact that the relationships between plant parameters are far from simple, make it practically impossible for the human operator to maintain optimum operating conditions at all times. Conventional instrumentation techniques have been developed to a very advanced degree in order to help with this problem, but their limitations are now being reached and an alternative approach is required.

If one examines a number of industrial process control problems, there emerges a pattern which may well be surprising. The functions of a plant operator can be divided into two groups. The first consists of those which are performed in accordance with some set of rules which could, if necessary, be defined in simple terms. The other group is formed from problems which require experience and intelligence for their correct solution, but which cannot be easily expressed. It is this facet which the human operator is best suited to solve, but unfortunately, due to the amount of time that has to be spent on the more mundane operations, there is little left for the others. In any case, it is the results of these mundane operations that provide the information to help solve the more complex problems and hence they must be performed first.

Thus one of the basic problems of industrial process control is to reduce the volume of routine work the operator has to do and allow him more time to exercise his skill and judgment for performing that part of the overall operation which is best suited to his abilities. As a result of this approach, it may well be found that some aspects of the problem, which previously were not fully understood, can now be analysed and relegated to the routine problem group. Thus the boundaries of knowledge can be gradually extended and so enable the product and

*Panellit Ltd., Elliott Automation Group.

economy of the plant to be continually improved.

An interesting example of this basic approach is in air traffic control, where the controller spends about 60% of his time performing simple routine operations. This allows him only 40% of his time to perform his primary function of controlling the paths of aeroplanes in flight. By using a computer to help in these routine operations it is estimated that only 30% of his time will be spent in performing these functions, thus almost doubling the amount of time he has to control aircraft movements.

Digital computers

An ideal aid to the solution of these routine problems is the digital computer. This device is so designed that it is capable of performing a series of simple operations at extremely high speed. Having often been referred to as an 'electronic brain', the computer has been shrouded by a mystical aura of popular misconception, which has frightened many away by its imagined complexity. In fact, a computer, in common with nearly every other great advance in science, is basically a very simple device.[1] It can be considered as a very simple-minded clerk who will do only what he is told, but will operate at a very high speed and with absolute accuracy. In addition, this simple-minded clerk also has the ability to make a few very simple decisions, such as whether a number is zero or whether it is negative.

Since our clerk has to be told what to do, it is necessary to provide him with a list of instructions. This is formed from a selection of the basic operations the computer can perform, for example: add two numbers together, multiply one number by another, subtract one number from another. The basic operations available will depend upon the particular computer being used. It is, for instance, not essential to have a separate instruction for multiplication, as this operation can be performed by successive addition. However, a multiply instruction facility will enable this operation to be performed much more rapidly. Thus, depending on the use for which a computer is designed, so various composite operations will be provided.

The preparation of the instruction list, or the programme as it is generally called, is quite a skilled operation. The problem must be analysed so that it can be broken down into a series of basic computer operations. This must also take into account the computer limitations of speed and storage capacity, and much ingenuity has to be shown in writing a practical programme.

Having prepared the list of instructions for the clerk, it is necessary to present them to him in a form that he can understand and in a position where he can have access to them. The internal language used by the computer in performing its operations is binary; that is, there are only two significant states (as opposed to 10 in a decimal system). Thus the information can be presented to the computer by means of punched paper tape, the presence or absence of a hole providing a binary coding. The holes on the tape are punched in accordance with a code or dictionary which provides the English/computer equivalent of the instructions.

The binary programme tape is read by the input system and transferred to the computer store. When the programme is started, each order is automatically passed in turn to a control unit which proceeds to perform the specified operation.

A basic functional diagram of a digital computing system is shown in Fig. 1. For the solution of a practical problem, information additional to the programme has to be fed into the computer. More often than not this information is available in a form other than binary, and hence the input 'box' must consist of something more complex than a punched tape reader. As long as the input information can be represented in some form of electrical signal, there are standard methods available for converting it into the binary form. Similarly the basic output would be in a binary form, but again the output 'box' can consist of the necessary decoding units to present the information for the operator in a more easily understood manner, for example in alpha-numeric form on a typewriter or a visual display.

The power and economy of a digital computer in an industrial control application lies in its ability to deal rapidly with vast amounts of information. By using sampling and time-sharing techniques, the computer can accommodate a large number of inputs and control loops without each having to have independent units of hardware. When further inputs or control loops are required, these can be added with a minimum of expense, as in general all that is required is to bring signals from the additional points and feed them into the computer. In addition, the programme may have to be modified to deal with the extensions. An Elliott general-purpose computer is shown in Fig. 2 (main cabinet).

Analogue computers

Although digital computers are far more adaptable to complex process control problems, there is another type of computer called an analogue computer.

As its name implies, this operates by forming an analogue of the problem. Continuously variable voltages and currents are used to represent the quantities involved, and with amplifiers and other circuit elements a model of the plant is made. Thus it is possible to investigate the operation of the plant, and the interdependence of the various parameters. This is

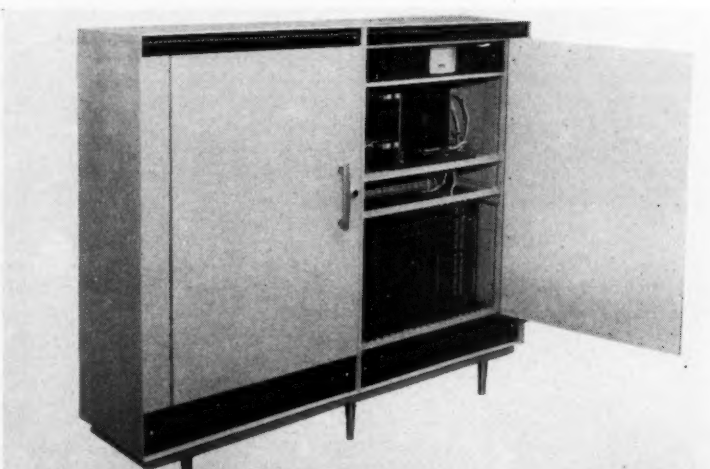


Fig. 2. Elliott 803 general-purpose computer showing the 4096 immediate-access magnetic core store. Each arithmetic operation takes about ½ mS.

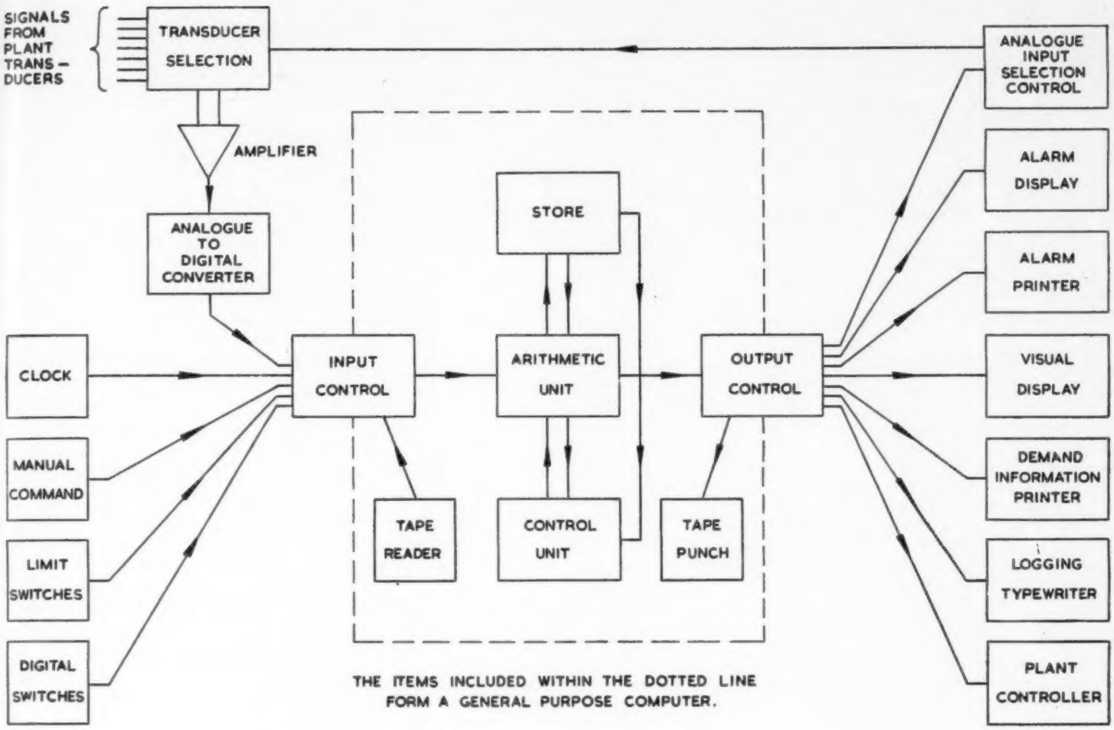


FIG. 1 BLOCK DIAGRAM OF A COMPUTER CONTROLLED DATA PROCESSING SYSTEM

obviously a much better way of examining a process than by actual experiment on the plant itself, where it is extremely difficult to control all the variables, and be certain of being able to completely repeat a given experiment. However, the formation of the model does require a certain knowledge of the plant operation, which can be gradually improved by successive approximation.

For laboratory investigations of a plant, an analogue computer may well provide a better approach.[2] Often it is the results of this form of investigation that produce the system operating equations, and thus enable the programme to be written for the digital computer.

The main disadvantage of analogue computers when applied to on-line process control applications is the lack of long-term storage facilities. It is also difficult to apply time-sharing techniques.

Process monitoring and control

The methods of applying a computer to process control are many and varied.[3] These can, for the purpose of the present discussion, be reduced to two: (*a*) fixed programme systems and (*b*) digital computer-controlled systems.

In a fixed programme system, the operations of monitoring and control have been fully defined before the system is constructed, and the required performance is obtained by including the necessary logical configurations and hardware. The latter can be quite large as, for instance, can be seen from the fact that for integration each input will require its own integrator, which cannot be shared amongst all integration points. In the digital computer system, the integration is performed by the arithmetic unit in association with the store and is thus effectively shared by all the inputs. Should a change be required to a wired-in programme, a major rebuild may result, with the system out of action for a considerable period.

On the other hand, a digital computer-controlled system has all the flexibility of a computer with considerable sharing of hardware between the inputs. The programme is held in the store of the system, and can be simply changed. Hence, as further knowledge is obtained, it is possible to make rapid adjustments to the programme with the minimum of interference to the plant. This can be achieved by alternate programme techniques, referred to in more detail later, or simply by reading in a new programme. Should the new programme not give the required results, it is easy to re-enter the original programme. With a 'wired-in' programme system this is obviously not so simple.

It can be seen, therefore, that a fixed programme system can best be applied to such problems as data acquisition, logging and alarm indication, which are relatively simple logical operations. The complexity and, of course, cost rise quite steeply if additional facilities such as alarm memories or integration are required. Fig. 3 shows a *Panellit* fixed programme monitoring system. Table 1 gives approximate cost of monitoring process variables.

'On-line' and 'off-line'

With a fixed programme system, arrangements can be made to present the collected data in a form which can be further analysed. For example, the data can be recorded on to punched paper tape which is then taken to a computer for analysis. In this case the collection of data is called an 'on-line' operation, as it operates in relation to real time, whereas the subsequent analysis is 'off-line', as it is quite unconcerned with actual time. With a computer-controlled system, the whole process of data collection and analysis is 'on-line', with the result that corrective action can be taken with the minimum of delay.

The difference between 'on-line' and 'off-line' operations can perhaps best be appreciated by considering an example from everyday life. A shorthand typist is operating 'on-line' when taking down a letter, as she has to keep up with external random impulses, in this instance someone dictating. When she comes to type the letter from her shorthand, she is now 'off-line' as the process is not dependent on any other stimulus. In the first case, if her thoughts wandered, a section of the letter would be lost, whereas in the latter case the typing process would just take a little longer.

There are certain sections of a data processing system which are common to all the various forms of computer-controlled systems. The smallest system would consist of:

(1) A method of examining the signals from the plant variables.

(2) An amplifier.

(3) A digitiser for converting the analogue signals from the plant variables to a digital form.

(4) A method of presenting the measured information in a form that can be understood by the operator.

(5) A programme unit.

These items will now be considered in detail.

Input selection

In very few—if any—processes is it necessary to examine a measuring point continuously. However, with standard indicating meters the capital cost of a meter is comparatively small and it is normal to have one meter per point.

With instruments like chart recorders the capital cost is more, and a certain degree of economy is attained by sharing the recorder amongst a number of measuring points. To accomplish this practically, it is necessary to use a sampling technique. By this method each of the measuring points is measured in turn and the reading recorded on the chart, before proceeding to the next point. After the last point has been examined, the first is looked at again and the process repeated. The limitations of such a system are two-fold:

(1) The minimum measuring period for each point is determined by the time it takes the instrument to measure it and record it. During this period the measured quantity must be substantially constant. However, this is not strictly necessary with pure analogue indicators, but is essential if the value is to be digitised. The next limitation will normally cover this point.

(2) The time interval between successive sampling of the same point should be such that a true representation of the signal can be obtained. This will be approximately so if this interval is less than a quarter of the periodic time of the highest frequency component.

With the electro-mechanical systems employed on temperature recorders the first period is about 1 to 5 sec. and for, say, a 20-point recorder, the second period is 1 to 2 min. approximately.

Table 1. Approximate Cost of Monitoring Process Variables

Method of measurement	*Cost of equipment per monitored point* *
	£
Conventional meter ..	10
Multipoint recorder ..	25
Data logger (fixed programme)	50 to 100
Computer-controlled system	100 to 200

* When comparing the costs shown, the additional facilities provided over and above simple indication must also be borne in mind.

As the number of process variables increase, a rather more sophisticated system is required, but the same basic approach of sampling is used. This enables the most economic arrangement to be obtained with the maximum sharing of equipment.

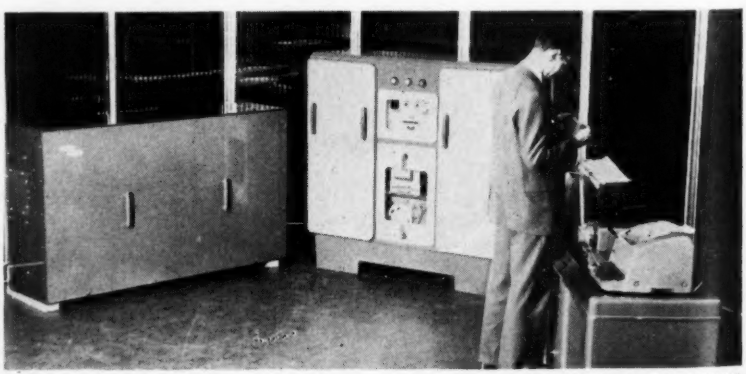
Every point in the plant which it is required to monitor is connected to the measuring equipment through a switch. Only one switch will be closed at a time.

The switches themselves are normally formed by stepping switches (or uniselectors) or relays. With the former a maximum scanning rate of 10 to 12 points/sec. can be obtained, whereas with suitable relays this can be increased to 100 points/sec. To provide reliable operation the contacts must be gold-plated, thus ensuring a low resistance connection. With relays, mercury-wetted contacts can be used providing a 10-fold increase of life over gold. To ensure isolation between the input points and help to suppress noise, these switches should be of the double-pole type.

Amplifier

Having now selected one input, its value can be measured. Depending on the amplitude, it may have first of all to be passed through an amplifier. This has certain advantages in that (1) the amplifier can be designed to have differential input, thus removing the major part of the noise, and (2) the output signal is single-sided and completely isolated from the input. The disadvantage is in the design of the amplifier which is far from easy.

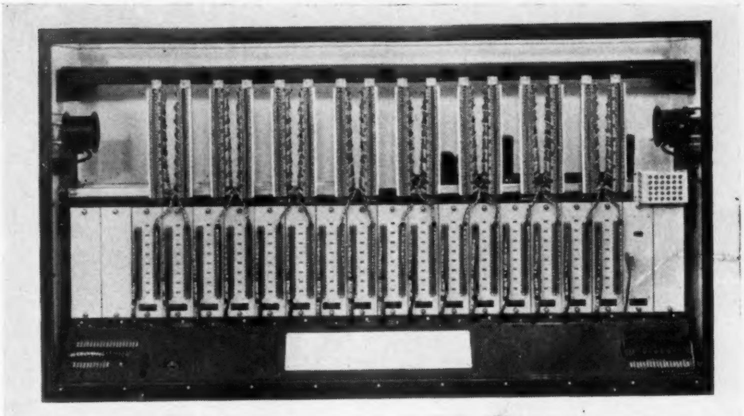
A typical specification for such an amplifier is tabulated in Table 2. In addition to these requirements it is essential that the amplifier is capable



(Courtesy: Elliott Bros. (London) Ltd.

Fig. 3. The programme unit in the centre digitises information from plant transducers

of having its input short-circuited or open-circuited for long periods without any detrimental effect. These two states are possible effects of transducer failure, and the open-circuit condition will occur in any case between sampling of successive inputs. It is often advantageous to group the amplifier and input selection close to the measuring points. This will simplify the cabling problems and provide a single high-level signal to the data processing system proper, which may be situated a considerable distance away. Thus the amplifier should also be capable of feeding a long cable which may well present a high capacitance. Fig. 4 shows a junction cabinet for terminating the field wiring from 128 transducers. The cabinet contains the selection relays and amplifier. Fans are provided to keep the temperature uniform, so that the cabinet forms the cold junction when using thermocouples.



[Courtesy: Elliott Bros. (London) Ltd.

Fig. 4. Junction cabinet for terminating the field wiring from 128 transducers

Digital conversion

In equipments of the type under discussion it is easier and simpler to deal with the digital equivalent of the measured quantity rather than the analogue signal itself. Conversion to the digital form can be performed very rapidly using a solid-state digitiser, and would take in the order of 2 mS. to present the analogue signal as a 12-bit binary or binary/decimal number. With such a converter the resolution obtainable is 1 part in 4,096 with an accuracy better than 0.1%, an improvement on that obtainable with conventional instrumentation.

Output

Having measured the input and produced its equivalent reading in binary code, it is a relatively simple matter to present this information to the operator in a readily understandable form. This can be by visual displays or printed on a strip printer or typewriter, depending on the particular requirements.

Table 2. Specification for Typical Amplifier

Gain	10 to 1,000
Frequency response	D.c. to 40 c.p.s.
Input impedance	>3 M.ohm
Output impedance	<5 ohm
Input	Balanced and floating
Output	10 V. max.
Drift	<3 μV.
Noise	<5 μV.
Common mode noise rejection	100 to 150 db.
Series mode noise rejection	50 db.

The simple method of operation would be to print out the value of each point as it is measured. The speed of operation of the printer would govern the scanning speed, but the quantity of material produced would be prodigious. Most of it would be of little interest, as normally the operator is only concerned in a measured point if it has deviated from the normal. By extending the system to include alarm scanning, this facility can be provided. To each measured point, or group of points, alarm levels are allocated. More than one can be provided for each point if required, and the actual levels can be preset. By comparing the measured value with the stored value of the alarm level, the state of the input can be determined and, if an alarm condition has occurred, this can be indicated. Usually the time, point number and value would then be printed on a typewriter in red as well as sounding an alarm bell. When the point returned to normal, a similar print-out, but this time in black, would indicate this. With this facility it is no longer necessary to print out information regarding every point for the operator to examine and see if any alarm condition occurs, for the system is quiescent—at least as far as the operator is concerned—until it is necessary to draw his attention to some deviation. A periodic print-out of every point can also be provided to give historical records.

The operation of the logger can be adapted, especially with the aid of visual displays, to form a digital voltmeter where on each scan the value of the selected point is up-dated. Alternatively the scanning can be stopped and continuous indication of the required point can be obtained.

Output devices can be easily multiplied in variety and complexity, but it must be remembered that every facility requires its own programme hardware. However, as stated earlier, this does not apply with a digital computer-controlled system where the vast majority of the additional logical requirements are always available.

Programme unit

The heart of any data processing system is in the programme unit. For a simple system a 'wired-in' type of programme unit can be used, but as the system is expanded this rapidly increases in complexity.

The specification of the system has to be arranged so as to form a simple logical list of elementary operations. Each operation is then translated into the equivalent circuit configuration and the resultant combination of hardware forms a fixed 'wired-in' programme. As an example of the size of such a programme, a data logger for scanning 128 inputs at 5 points/sec. with alarm monitoring and indication and periodic print-out of all values on an electric typewriter would need about 200 logical operations.

As the facilities of a fixed programme system are extended, the programme becomes very complicated and large, and the price of the equipment starts to rise quite steeply. For a system of 200 or more inputs with integration and analysis, the cost will compare with a computer-controlled system, especially when its additional flexibility and capacity are borne in mind. For the same reasons the fixed programme system can perform little analysis of the measured quantities and, similarly, if a fully closed loop system is required, only elementary process control can be achieved.

Design of Heat Exchangers by Digital Computers

By D. K. Houtby,* B.Sc., A.M.I.Chem.E.

It is becoming increasingly important, in order to save time, to apply computing techniques to the design of chemical plant. A most suitable plant for design considerations is the heat exchanger—a completely self-contained unit for which all relevant design criteria are specified by process considerations. This article outlines a project currently undertaken at the Bradford Institute of Technology to evolve a universal programme by means of which sizes of heat exchangers can be determined using a digital computer. Present indications tend to show that, on a cost basis, computer design can just break even when compared with manual computation.

IN considering the application of computers to chemical engineering design problems, probably the most logical first choice is in the rating of heat exchangers. A heat exchanger is, as regards design considerations, a self-contained entity for which all the relevant design criteria are specified by process considerations. The nature and size of the interchanging streams are fixed, the desired temperatures are known or must be assumed, and the problem resolves itself into that of a straightforward determination of size required. The steps involved in this are the same for all heat exchangers, quite independent of the size or type of process involved, so that any programme derived for the design of heat exchangers will be universal. In view of the large numbers of heat exchangers involved in chemical processes, this is obviously a problem of wide applicability from which a great deal of benefit would accrue by the application of automatic computing.

Description of computer

The machine in use at the Bradford Institute of Technology is a *Stantic Zebra* digital computer. This has a drum storage of some 8,000 words, each of 33 binary digits, and a word time of 312 microseconds. The programme being developed is written in an autocode (in this case termed 'simple code') which gives times of common arithmetic processes such as the addition or multiplication of two numbers of about 20 to 40 m.sec./operation. The decision for using this code was dictated by two considerations. Firstly, it is a straightforward notation which corresponds very closely with normal mathematical procedure. This means that it is relatively easy for even major alterations to be made to the programme in the light of experience. Any new programme involving the number of steps and considerations that are required to design a heat exchanger must necessarily be of an exploratory nature initially, and therefore it is essential to be able to incorporate amendments or test alternatives quite easily. The time taken to write the programme is considerably reduced by using a simple code, but this code, being an interpretative one, is comparatively slow. It may therefore be that once a programme is finalised it will be justifiable to undertake the translation of it into the more efficient general machine code. Due to the expense involved in this, though, it is far preferable that all snags and teething troubles should first be ironed out and a clear conception obtained of precise details of the results required and methods used. The second advantage in developing a programme in simple code is that there is no necessity, using this system, for the scaling of numbers. Numbers are handled in a floating point form, that is to say, as a mantissa and index, so that the range of numbers available far exceeds anything likely to be met.

The use of a simple code reduces the storage capacity of the machine. Each instruction and number occupies two word positions on the drum, whilst a sizeable proportion of the total capacity is required for standard and interpretative programmes connected with the simple code. It is desirable to keep the total number of instructions and numbers below 2,000, although up to 3,000 may be accommodated if certain facilities normally associated with the simple code are sacrificed. So far this has been found adequate to deal with heat-exchanger design.

Mathematical relationships

Many equations have been developed for heat transfer and pressure drop in heat exchangers. These are well covered in the literature, and it is of little consequence which particular equation is used as far as adaptation to computer techniques is concerned. It is, however, important to remember that the computer is merely a mathematical tool. It will calculate rapidly and accurately the answer to a given equation, but it cannot rectify any errors or inaccuracies in the equation. The solution of the equation will be given to a far higher degree of accuracy than can be obtained from either normal hand calculations, graphs or nomograms; but if there are inaccuracies in the original equations, these will be faithfully reproduced in the answers. For this reason it is desirable initially to decide clearly which relationships are to be used and to realise that any inaccuracies contained in these equations are fundamental limitations to the answer.

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All correlations that are to be used in the calculation must be in algebraic form. In order to ease the load on normal calculation and to make the design process quicker, it has been the practice in the past to reduce relationships wherever possible to a graphical or nomographical form. A typical example of this is in the correction of logarithmic mean temperature differences for multi-pass exchangers. The expressions for this, whilst not complicated mathematically, are long and unwieldy and, within the limits of accuracy required, a lengthy and time-consuming solution of these equations is hardly necessary. It is for this reason that graphs relating parameters have been developed and are in universal use. From the computer point of view, however, such graphs are of no use, and the original relationships must be reverted to. Due to the high speed of computing nowadays, the length is not the paramount disadvantage that it was previously.

It may be, of course, that in some cases the original derivations of the graphs are lost in antiquity and therefore, just as in the past a great deal of effort was devoted to translation from algebra to graphs, the reverse must take place nowadays. The modern mathematician is in the fortunate position that he can use the computer by feeding to it a limited number of values from the graph to give an equation that fits the curve.

Again, it must be remembered that all decisions taken by the computer must be based on some quantity. A simple example of this is, for instance, that, if the Reynolds number inside the tubes exceeded 10,000, the flow may be assumed to be turbulent and the expressions given to the computer for this type of flow would be applicable. This type of criterion can be worked out by the computer but, since it possesses no intuition, it cannot make those choices which the chooser would personally attribute to 'experience'. The machine will in every case interpret the criteria most rigidly. If the Reynolds number is 10,000.1, it will assume turbulent flow and proceed with the calculation. If, however, the Reynolds number is 9,999.9 it does not possess the ability to argue that this is near enough. Therefore, it will reject turbulent flow and proceed with whatever instruction has been given to cover this eventuality. It is important to remember, therefore, that if the designer is prepared to tolerate slight discrepancies from the normal figures these must be built into the programme and the specific criterion given this desired figure. It is also important to remember that every eventuality must be covered. If the machine is to test for turbulent flow, then some course of action to be followed in the event of a failure of the test must be supplied. Because of this, it is useful that, if the programme be discontinued due to a failed test, some indication of the reason for not completing the programme be given.

No general rule can be formulated on the question of whether it is preferable in a particular case to build into the programme a table of corresponding values of properties rather than to use an algebraic expression. The disadvantage in using an algebraic expression derived by mathematical techniques is that this expression generally will be a 'best fit' relationship in which the error at any given value is within acceptable limits. In some cases the expression may be well within the acceptable limit and may, in fact, be very near to the actual value for the greater part of the scale. On the other hand, the error may fluctuate widely above and below the correct value, giving a value which is only barely acceptable. The technique of inserting a number of values of one variable, giving access to the same number of the corresponding variable by placing the two in constant relative positions in the store, is probably of most use when the first variable only has a discrete number of possible values. If the first variable can have any value, then rounding off with a corresponding possible error will have to be done before the table can be used. The storage of tables in a programme occupies a considerable amount of storage space, which restricts its use to a certain extent. Errors involved in rounding off may in fact exceed errors in the derived algebraic expression, thereby making the latter more attractive. In all cases, however, the table of figures would have to be fed to the machine at the commencement of calculation, and whether the time taken to do this is of any significance will depend upon the number of exchangers to be calculated in each batch. The decision, therefore, whether to use expressions or tables must be considered in every case on its merits.

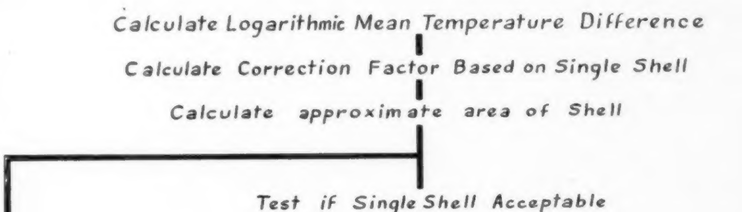

Fig. 1. Typical Computer calculation

Programme size and scope

Possibly the most difficult decision to make concerning any programme is its size and scope. This will, to a certain extent, depend on the purpose for which the programme is to be used, and the frequency with which particular cases occur. At the simplest extreme it is possible to produce a comparatively short programme which will design a simple single-shell heat exchanger of a particular type, providing the heat-transfer coefficient on the shell side is constant (*e.g.* steam condensing) and the tube side carries a given liquid under conditions of turbulent flow. Such a programme, however, would be extremely limited in its application. At the other extreme, a completely universal programme would be lengthy and complex with innumerable variations to be considered at each stage. Some of these variations might be comparatively rare, but nevertheless their consideration and inclusion would occupy a certain amount of time, thereby considerably complicating the execution of the more common cases. Whether the time involved is justifiable must always be considered prior to the inclusion of any variable.

The main factors that could be introduced into a programme and which have a bearing on its overall length can be approximately divided into the following six categories:

(1) For different types of heat exchanger, the relationship between available area for heat flow and the linear dimensions of the exchanger varies according to the type of exchanger. The simple types with fixed tube plates are used where differential temperatures can be ignored or allowed for by bellows or other devices. To overcome differential expansion problems, U-tube bundles may be used either in a minimum-sized shell or in an evaporator-type body. In either case, a restriction will be required on the number of passes allowed on the tube side. If the programme is to include floating-head exchangers, yet another expression or series of values must be included to allow for the different relationships between heat-transfer area and physical dimensions. In each case, facility must be built into the programme at each stage in the calculation where these considerations affect the figures so that the appropriate ones are used. The selection by the machine will probably be made by the use of a code number or numbers allocated to each type and the appropriate values will be stored in relative positions located by reference to this code number.

(2) The size of tube and layout on the tube plate are generally chosen arbitrarily with reference to the particular service. Again it will be necessary to typify all the combinations which it is desired to cover in the programme by means of code numbers. If the majority of exchangers which are to be rated are of one particular type (a standard tube size and layout), it may be advisable to have a programme which will deal with this case only. This will save the necessity of feeding to the machine the various code numbers typifying size and layout of tubes and type, and will shorten the programme by eliminating the necessity of making choices at several stages.

(3) The type of flow and phases to be covered by the programme may be restricted or, alternatively, for a general-purpose programme, it may be desired to incorporate all the eventualities likely to be met. Even in the case where it is assumed that only a liquid phase will be present, it is still possible to have programmes that will cater for turbulent flow only or both turbulent and laminar flow, possibly with extensions to cover the transitional zone. This case, however, differs from the previous ones because what is involved is a selection not between differing values of a characteristic, but between differing relationships, each of which will require a completely separate and distinct sub-programme. The choice will be made, moreover, on the values obtained from the calculations which have been previously made by the machine. Subsequently, even if particular circumstances are not covered in the programme, it is advisable to include tests in it, since it may not be obvious from the initial figures whether the type of flow, for example, falls within the scope of the programme. In this case the programme will cease at the point where the test fails, and should be so constructed to print out an indication of why, before passing on to the next exchanger. The programme being developed at Bradford includes both turbulent and transitional regions, and will probably be extended to include laminar flow (although this is of little industrial importance). Later it is hoped to develop programmes involving phase changes, but at present the feeling is that these will best be covered in a separate programme.

(4) The programme may be used for designing only single-shell heat exchangers, or may be so constructed as to allow for shells both in series or parallel. In the latter case, some specification must be given to enable a choice to be made. In the case of shells in series, this will either be in the form of a maximum shell area, or a maximum or minimum value of some suitable parameter. In the case of shells in parallel, this may be specified initially probably after the failure or unsatisfactory answer of a previous calculation, or will possibly be governed by pressure-drop requirements.

(5) Physical properties will be required for the streams. In the simplest form these can, in each case, be an average value which is regarded as a constant. As temperatures vary within the heat exchanger, the properties will vary and it may be advisable to include two or more values which are used with discretion in the programme, or to include the property as a function of temperature, utilising two or more constants. The latter case is especially useful where any of the expressions include values of properties at other than average conditions. It may even be considered that, in the case of some common substances, it is advantageous to have a programme in which physical properties are included in the main programme so that for each exchanger it is only necessary to specify the liquid by some reference number.

(6) The programme can be extended to include not merely thermal considerations but also possibly some mechanical design considerations. This is especially useful, for instance, with regard to inlet and outlet nozzles and impingement plates, and these in turn are related to thermal properties.

Programme and manual calculation

The actual course taken by a programme will resemble very closely the steps in the normal manual calculation. An example of a typical calculation is shown in Fig. 1. Alternative schemes are shown in Figs. 2*a* and 2*b*. As previously stated, a computer must have some fixed criterion on which to design and, in the case of single-phase heat exchangers, this is generally the pressure drop. In the case of the tube side, this is controlled by the number of passes and, in the case of the shell side, by the number and design of the baffles. An increase in either increases the pressure drop on that particular side and likewise results in an increase in the thermal transfer. It is assumed that maximum pressure drop will be specified for both sides and that the heat exchanger will

be designed with the maximum number of passes and the maximum number of baffles compatible with this. In this way, heat-transfer coefficients are maximised and the smallest possible heat exchanger will be stipulated.

It is necessary, as in the manual calculation, to have either an assumed overall heat-transfer coefficient, or an assumed area. The programme will then calculate actual coefficients or areas, as the case may be, and, if these are considerably different from the assumed, will repeat the calculation with the new values until agreement is reached. It is obviously desirable, therefore, that the initial guess should be of the right order so that the machine does not have to perform too many cycles. Likewise, the limits set on the agreement of the assumed and calculated values should be as wide as possible, so that another cycle is not undertaken for what is perhaps purely academic agreement. In view of the wide limits that are applicable even to the more reliable of the heat-transfer coefficient calculations, it is possible to set quite wide limits to the agreement and thereby achieve sizing with relatively few cycles.

The first step taken by the programme is to calculate the logarithmic mean temperature difference and correct it for single-shell multi-pass flow, for which expressions are readily available. If the data provided an assumed heat-transfer coefficient rather than an area, the next step will be to calculate from this and the corrected logarithmic mean temperature difference a corresponding area, and to test whether this is permissible in a single shell. If this test fails, then two or more shells must be tried until a satisfactory area per shell is obtained. With the area of heat-exchange surface in each shell settled, it is now possible to specify the number of tubes required. It is obvious that the diameter and length of each tube must be specified in the initial data and, if results are required for more than one size of tube, then separate calculations will be required for each. With the number of tubes fixed, using the pressure-drop limitations, the number of passes can be calculated.

In the case of floating-head exchangers this must be limited to even numbers only. From this, the size of shell may be determined either by looking up in a table of corresponding tube and shell sizes stored in the computer, or by using some correlation based on the average area occupied by a tube with due allowance for pass partitions. With the shell diameter specified, the pressure-drop specification on the shell side may be used to determine the baffle arrangements and the exchanger is then fully specified. In both tube and shell side pressure-drop calculations it is advisable to insert safeguards to prevent ridiculous answers as, for instance, a 12-in.-diam. 24-pass exchanger with $\frac{1}{2}$-in. baffle spacing. That this sort of thing can happen is one illustration of the computer's complete automation. Fig. 3 shows various shell side arrangements.

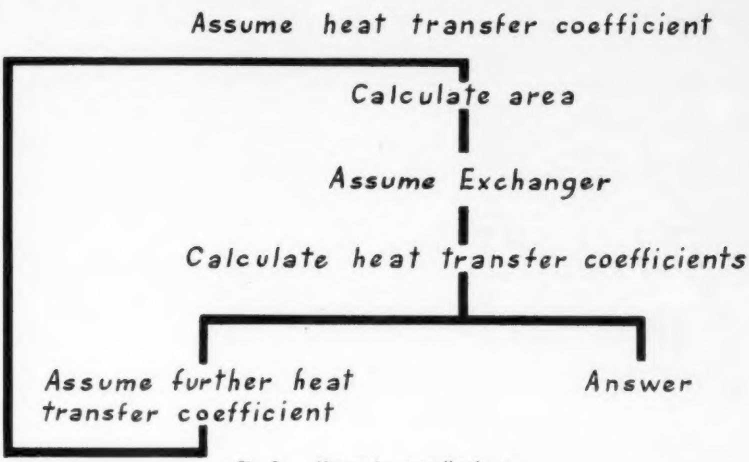

Fig. 2a. Alternative overall scheme

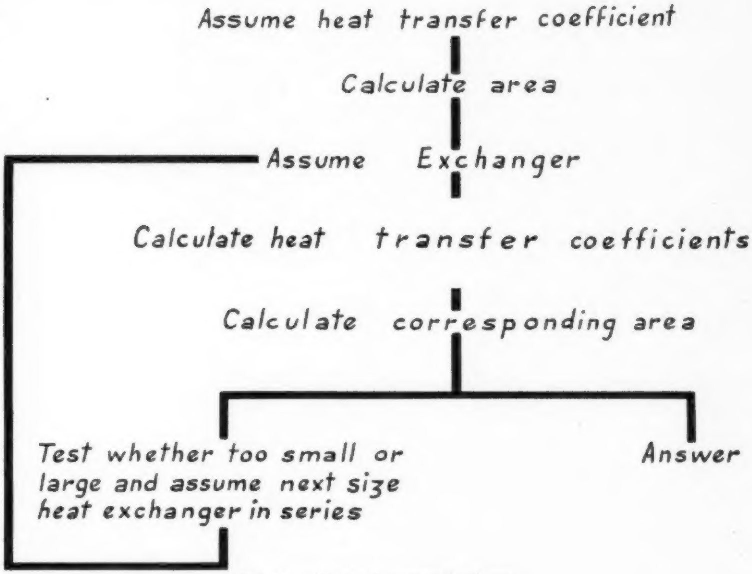

Fig. 2b. Alternative overall scheme

With the exchanger specified, it is now possible to calculate heat-transfer coefficients and, after summation, compare these with the original. If the error is too great, then the newly found coefficient is substituted for the original guess, a new area calculated, and the programme re-entered at the step where consideration is given to whether one shell is acceptable. Re-entry must be made at this point, since it is essential that, whenever a change is made, care must be taken that no previous decision is invalidated.

Design for commercial purposes

In the design of heat exchangers for commercial purposes, however, one consideration may make a rather different form of programme attractive. The majority of manufacturers have standard ranges of heat exchangers which,

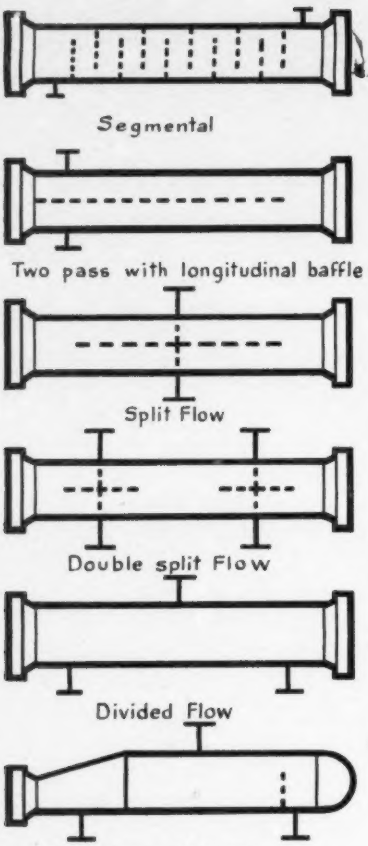

Fig. 3. Shell-side arrangements necessitate differences in programme

because of their uniformity, offer quite substantial cost advantages. In this case, it would be uneconomic to specify anything other than a standard size of shell and, in fact, it may generally be assumed that the whole number of tubes will be used in a given shell, as their omission would give little, if any, reduction in the cost. Even though T.E.M.A. standards no longer specify shell sizes, manufacturers will have their own standards, and this means in effect that there are only a finite number of exchangers from which to choose.

In this case, the programme, having determined the approximate area of each shell and the number of passes, will choose the nearest standard size. The calculation will then be based on this exchanger. If the heat-transfer coefficient does not give agreement, the programme will then try the next size smaller or larger, dependent on the direction of the error. This method saves the possibility of the computer trying the same size twice in its approach to the correct solution. Finally, the computer will give as its answer the size nearest to the ideal, although it can, of course, be set to give two answers, one being the size larger than the ideal, and the other the size smaller.

Costing of computer design

Present indications are that heat-exchanger design by computer can, on a cost basis, break even with manual computation. With the gaining of experience, enabling the programme to be streamlined, it is hoped that the cost of machine designing will be brought below that of manual working, and the conversion to normal machine code when the programme is fully tested will make considerable reductions in the cost. The future therefore appears bright, but even without this there are several features of computer design that are of sufficient attraction to justify its use.

(1) The answers given will be accurate within the limitations of the expressions, and human errors of calculation are eliminated.

(2) For each design, the computer will consider several alternatives and will produce the answer that approximates most closely to the criterion given. It will, for example, continue trying different numbers of passes until it exceeds the criterion, thereby establishing that the one actually selected is the highest. There is a tendency in human calculation to assume this without actually testing.

(3) The computer can provide more information in the way of intermediate results without any great extension of the programme. Since it will, in the course of execution, try alternatives above and beyond those finally decided, these can, if required, be output.

(4) Following from the above, it is feasible that, with these additional values at the chemical engineer's disposal, it will be possible to reduce the size of exchanger required for a particular service. This sort of decision can be taken with more confidence when exact and full figures are available.

(5) The programme, once written, is fully automatic and the feeding in of individual data can be made into a routine job so that the supervision and execution of the design can be carried out by non-expert staff. This will release technical staff for less mundane duties.

(6) The answers are produced much quicker than with manual calculation. This means that there is less delay in actual time between the receipt of details and the preparation of a specification.

(7) The extreme pressure put on design staff by the simultaneous receipt of several exchangers to size is avoided. Even if a major rush is experienced, the results will be available in a very short time, with far less aggravation to staff.

(8) With exchanger sizings easily available, it is possible for process designers to consider a greater number of alternatives in their schemes. In this way, the effect of altering process conditions can be studied in much greater detail, with far more knowledge of how they will affect plant costs.

Conclusion

From the above, it can be seen that the obvious trend in the future will be for routine sizings of this nature to be carried out on machines. An attempt has been made to give a brief idea of the considerations affecting and controlling the translation to mechanical methods. Certain refinements are still required and, no doubt, many improvements will be made but, provided careful consideration is given at all stages to the points mentioned, the problem is relatively straightforward and not in the least magical.

Symposium on polymer science

The Plastics and Polymer Group of the Society of Chemical Industry is arranging a symposium entitled 'Techniques of Polymer Science', which will be held in London on September 27 to 28, 1962.

Papers concerned with novel techniques will be especially welcome in the fields of polymer synthesis, analysis (including structural analysis) and physical properties.

Summaries of proposed contributions should be sent to the Convenor, Plastics and Polymer Group Symposium Sub-Committee, 14 Belgrave Square, London, S.W.1.

Gas industry statistics

The gas industry's statistics show that gas production was at almost the same level as in the previous year, but that there was an increase of about $12\frac{1}{2}\%$ in purchases of gas, giving an overall increase of more than $2\frac{1}{2}\%$ in total gas made and purchased. There was a slight fall of just over 1% in the tonnage of coal carbonised. Coke production, too, was at a somewhat lower level.

Safety Assessments in the Nuclear Industry

Part 2

By A. Quinton,* M.Sc., F.Inst.P.

In the first part of this article, which appeared last month, such safety criteria as the selection of site position and building construction were discussed. In the second part various other important safety aspects such as radiation shielding, contamination problems and the duty of the Health Physics Services are examined. It is pointed out that in the construction of any nuclear chemical plant, an overall statement of its design is essential for safety assessments and for the correct provision of safety facilities.

THE first principle in the assessment of shielding is to ensure that no worker receives more radiation than is necessary in the course of his duties; in any case, this radiation should be less than that permitted in the Ministry of Labour Factory Act—Ionising Regulations.[5]

In any area where men may be present for the full working week (40 hr.), the dose rate from all sources and all types of radiation must not exceed the limit for occupational exposure laid down in the recommendations of the International Commission on Radiological Protection.[6, 7] A brief summary of these levels was given in Table 1.

For each area of the plant an estimate is made of the total amount of radioactive material, the nature of the emission and the estimated dose rate in the operating area. The assessment of the design should ensure that the dose rates in the operating areas are reduced to acceptable values. Whatever the shield material chosen, its design and fabrication should exclude the possibility of a direct radiation path or of some hidden weakness due to reduced density (porosity in concrete) and particular attention should be devoted in this respect to breaks in the containment design to allow the entry of cables, pipes or ventilation ducts.

Gamma radiation and neutrons are highly penetrating and give rise to whole body hazard, and in any consideration of shielding they are of prime importance. The best shielding[8, 9] against gamma radiation is high-density material such as lead or steel, although concrete loaded with iron shot or barytes may be used. Neutron shielding requires a material rich in hydrogen atoms (water, *Perspex*, etc.), loaded with neutron absorbers (boron and cadmium), and it must be capable of slowing down fast neutrons, capturing thermal neutrons, and absorbing secondary radiations due to neutron capture. Where space is available, a mixture of iron and concrete shielding may serve the double purpose of construction and shielding, but where space is restricted it may be necessary to use more expensive and denser materials. In this respect a given mass of shielding is more effective if placed closer to the source.

If the design includes shield materials of low melting point, liquid materials or movable shields, the assessor should note whether adequate steps have been taken to prevent loss of shielding, leaving the operator exposed to excessive radiation. In many cases it is essential to incorporate in the design continuous monitoring fed into a recorder and an alarm circuit to raise an immediate alarm if loss of shielding has occurred.

If for various reasons it is not economical to give full shielding protection to a given area, there must be restrictive access to ensure that any worker, in the course of his duties, does not get doses in excess of the values indicated in Table 1. If the plant is processing sufficient fissile material for a criticality incident to be possible, the design should ensure safety by geometry wherever possible, but failing this, by very strict instrumental and operational control. It is not normal to provide shielding against a criticality incident, but there are occasions when it may be worth while to use shielding to meet routine requirements and a possible criticality incident.

One aspect of shielding of importance in the nuclear industry is that apparatus behind fixed shielding needs to be extremely reliable, as its maintenance may be very difficult or impossible. It is for this reason that most items of equipment are tested rigorously by radiography and other means to ensure their reliability.

Contamination

It is necessary to design against the production or spread of contamination, to choose surfaces which make any necessary decontamination easy and, finally, to make provision for the clean-up of contamination.

This section will consider contamination problems in more detail. Contamination usually arises from alpha and beta emitters, and Table 2 indicates the maximum permissible levels of surface contamination, and these have been calculated to ensure safety from direct radiation effects and from inhalation and ingestion hazards.

For any particular chemical plant an estimate should be made of the total quantities of radioactive isotopes which can escape into the maintenance or operating areas.[16] The design should be such that the probability of air contamination levels exceeding those laid down in the recommendations of the International Commission on Radiological Protection[1] is very small. Table 3 indicates the maximum permissible concentration for some radioactive materials in air and drinking water for exposure of radiation workers.

If a worker is called upon to enter an area where the levels laid down in Tables 2 and 3 are exceeded, he would

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normally wear some form of protection. The amount of protection would vary according to the circumstances. At a low level it may only be necessary to substitute factory clothing for private clothing, but where the conditions are extremely severe, the worker would be provided with special equipment, often referred to as a 'frogman's suit', which would give him full protection against contamination over a limited period. The purpose of protective clothing is to safeguard the worker against the contamination. It does not necessarily give any real protection against external radiation. A protective suit made from PVC does not shield the worker against radiation; the material of the suit prevents direct contamination of the skin. If a positive pressure is maintained within it, further protection is given because there is a greater separation between skin and contamination and an air leak must be outwards. Where the operation justifies it, the worker would also wear gloves and in certain cases have an independent air supply. The material selected for use in an area where there may be contamination should have a surface which is smooth and impermeable, resists contamination and is easy to decontaminate. There are, however, other considerations such as resistance to acid, water and abrasion. In practice it is often necessary in the design to select that substance which incorporates most of the desirable features. The adherence of radioactive contaminants to a surface may be influenced by chemical groups or by physical absorption increased by potential difference. For example, a ceramic-containing silicate will often possess sodium grouping at the surface and a contaminant will either attach itself to this sodium grouping or replace it. On certain surfaces a potential difference (zeta potential)[18] may be proved to exist, and experiments have shown that, if this is significantly negative, metallic contaminants, usually positive, will adhere to it. The greater the negative potential the more strongly adherent is the contaminant. In this respect, PVC plastic tiles are superior to a granolithic finish, although they may not have superior resistance to abrasion. Much work has been done on different paints and it is possible to recommend paints which are superior from a radiation resistance or decontamination point of view than ordinary standard paints. Chlorinated rubber-based paint is resistant to chemical attack and water, and is easily decontaminated. It is not, however, suitable for high temperatures or where an abrasion resistance is required. Epoxy resin-based paints give a smooth, non-porous surface resistant to abrasion and shock damage and are resistant to thermal conditions up to 100°C. Strippable paints are also available; these give non-porous surfaces, resistant to abrasion and chemical attack and they may easily be removed by a peeling action.

Based on the external radiation/contamination problem associated with the materials and the process, a decision has to be made on whether open bench work, ventilation hoods and similar precautions are adequate or whether more elaborate steps such as glove boxes, shielded cells, filter systems and remote handling are necessary. The best design will provide for industrial and radiological safety with the minimum inconvenience for the worker to do his job.[15]

Table 2. Maximum permissible levels of surface contamination

Radioactive material	*Personal clothing in active areas, low-activity areas, μc./sq.cm.*	*Contact clothing high-activity areas, μc./sq.cm.*	*Skin*
Principal alpha emitters	10^{-5}	10^{-4}	10^{-5}
Low-toxicity alpha emitters ..	10^{-4}	10^{-3}	10^{-4}
Beta emitters	10^{-4}	10^{-3}	10^{-4}

NOTES:

(1) In the table the figures in column 3 are ten times higher than column 2. The time spent in contact clothing or in high active areas is kept to a minimum and, when leaving such areas, a monitoring check is made.

(2) At the discretion of the health physicist in charge there can be some relaxation of the above levels either on the grounds of limited area contamination or because the contamination is firmly fixed to an inanimate surface.

Table 3. Maximum permissible concentration of radioactive materials in air and drinking water for exposure of radiation workers

Element	*Critical organ*	*State of contaminant*	*Maximum permissible concentration*	
			Water, μc./ml.	*Air, μc./ml.*
C^{14} (CO_2)	Fat	Soluble	0.02	4×10^{-6}
Fe^{59}	Lung	Insoluble	—	5×10^{-8}
Co^{60}	Lung	Insoluble	—	9×10^{-9}
Sr^{90}	Bone	Soluble	4×10^{-6}	3×10^{-10}
Zr^{95}	Lung	Insoluble	—	3×10^{-8}
Nb^{95}	Lung	Insoluble	—	1×10^{-7}
I^{131}	Thyroid	Soluble	6×10^{-5}	2×10^{-9}
Cs^{137}	Whole body	Soluble	4×10^{-4}	—
Rn	Bone	Soluble	4×10^{-7}	3×10^{-11}
U (natural)	Lung	Insoluble	—	6×10^{-11}
U (enriched)	Lung	Insoluble	—	1×10^{-10}
Pu^{239}	Bone	Soluble	10^{-4}	2×10^{-12}

NOTE: The values given in the table assume that the operator is exposed week by week for a long period. Over short periods contamination levels several magnitudes greater may be acceptable, but in general where the hazard is known to exist the operator should wear protective equipment. Where there is reasonable doubt, monitoring of the area should always precede the entry of unprotected personnel.

Health physics services

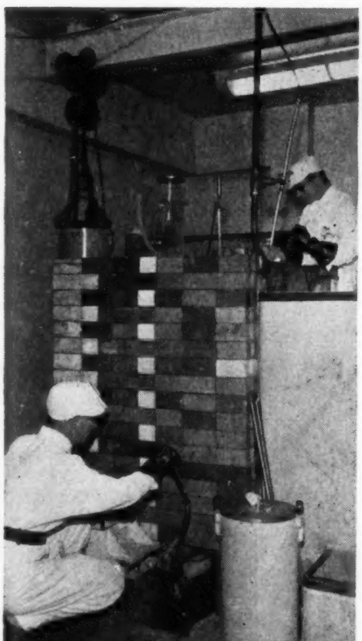
The prime duty of the health physics service is to ensure the radiological safety of the workers. If the design is unsatisfactory, monitoring measurements will demonstrate the need for modifications. In the event of modifications not being feasible, the health physics service will advise the management on a satisfactory operational control.

The design of the building should include a room set apart for the health physicist and facilities for the storage and testing of measuring instruments. These would normally

include portable instruments for the measurement of gamma and neutron radiation, alpha and beta contamination and air sampling units.[14]

The installed shielding must be designed and checked to ensure satisfactory radiation levels. It is necessary for the health physics service to carry out actual measurements to ensure the absence of weak spots in the shield, such as those attributable to porosity in concrete or direct shine through minute gaps in the shielding. The health physicist must pay particular attention in his measurements to those parts of the shield that are near cables, ducts or other penetrations. Early measurements prior to start-up are usually carried out using standard cobalt sources, but these will be followed up by radiation surveys when the production is building up.

The design assessment checks upon the correct use of materials in the various plant areas to ensure a minimum contamination problem. The health physics service should have sufficient facilities to ensure that there is no deterioration in clean conditions either by faults in design or by faulty operational control. There can, for example, be a check on the ventilation system to ensure the necessary flow of air to prevent back diffusion of contamination.



[Courtesy: U.K.A.E.A.

Fig. 3. Bins for uncontaminated equipment and clothing

If the proposed plant is to be at a site where centralised decontamination and laundry facilities exist, the design should provide for the sorting out, monitoring and packaging prior to despatch to the central facilities. The principles to be followed are:

(1) To prevent uncontaminated equipment and clothing being mixed unnecessarily with contaminated apparatus. The provision of properly marked bins is useful in this respect (see Fig. 4).

(2) To prevent the spread of contamination due to the movement of contaminated apparatus over clean areas. Relatively simple measures, such as containment in polyethylene bags and the temporary covering of floors with PVC sheet are effective for this purpose.

Where centralised facilities do not exist and particularly for research and development buildings, there should be local facilities for decontamination. The design should provide for washing facilities convenient to the source of contamination, as fresh contamination is easier to remove. In most cases the provision of water is all that is necessary, but stubborn contamination may often be removed by special solutions containing detergents or chelating agents. If the design provides for adequate working and storage space, sinks and monitors, good housekeeping and strict operational control will overcome the contamination problem (see Fig. 5).

Further points to be checked in the design proposals include:

(1) The segregation of radioactive liquid effluents from other effluents.

(2) A positive break between the supply of clean water and the water used in a contaminated area.

(3) The provision of a personnel air supply which can be guaranteed free from foreign bodies, including radioactive contamination. Ideally this supply should be separate from the process air supply.

There will normally be a central organisation for the issue and measurement of film badges for the recording of personnel doses. The health physics room, already referred to, may be used for the issue and collection of films. In the absence of a centralised facility there will be a need for additional space to run a film badge service. If criticality is a real hazard, there will also be a need to issue neutron measurement devices.

Public health

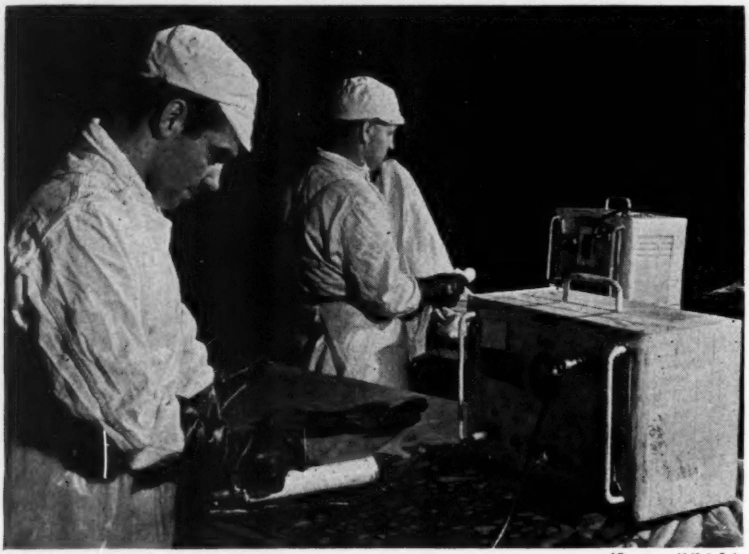
There should be no public health hazard arising from routine operation of the plant. It is necessary to study possible accident conditions to ascertain the total quantities and nature of any release and the consequent public health hazard.

It is necessary for the operator to have an authorisation[3] from the appropriate Ministry for the disposal of liquid and solid waste. This authorisation will normally specify the total amount of activity allowed to leave the site during a three-month period and also an upper limit on concentration. The authorisation is calculated to ensure that there will be no unacceptable damage to any member of the public. In the case of solid waste, the methods of transport and burial will need to be studied and agreed. There should be provision for the keeping of records and for these to be available to the appropriate Ministry. The problem of gaseous effluents is more difficult, as there is no equivalent to the liquid hold-up tank. The design must provide for monitoring of all radioactive effluents and for periodic environmental monitoring. The aim of this dual control is to detect any contamination of air, surfaces or agricultural products which could ultimately present a hazard to people living in the neighbourhood.[13]

An emergency may arise from an explosion or fire, or from a criticality incident if sufficient fissile material is present. In nuclear industry a fire involving radioactive material can be much more serious, due to the spread of contamination downwind.

The design plans should include a building control point and a site control centre. The first aim of the emergency plan should be to bring the plant under control and to protect the workers. The emergency organisation will have the additional duty to assess the spread of contamination beyond the site boundary by a study of meteorological conditions confirmed later by monitoring. Emergency plans to safeguard public health, including the necessary local liaison, should be studied in advance of the operation of the plan and should be put into action by the site emergency organisation if this proves necessary.[10, 11, 12]

As part of the operation of the chemical plant, it will be necessary to transport radioactive material within buildings, between buildings and from one site to another. It is desirable to transfer radioactive materials over short distances without breaking the containment but, if this is not possible,



[Courtesy: U.K.A.E.A.

Fig. 4. Clothing being monitored at the Windscale laundries

transport containers should preferably be of a standard pattern and, in any case, should conform to the international regulations.[17] The regulations drawn up by the public transport authorities conform to the international recommendations and these, of course, will be mandatory between sites unless private transport is being used. Under all circumstances there should be no significant hazard to members of the public. The main requirements are:

(1) The external radiation at the surface of the container should be small and there should be no significant contamination.

(2) The container should be so designed that there can be no possible loss of radioactive material even if the container is subject to fire and mechanical damage.

(3) In the case of fissile material the relevant precautions should be taken against a possible criticality excursion.

Overall safety assessment

It is important to have an overall statement of the design and proposed working of the plant so that the project can be considered as a whole. The operator should be aware of any limitations imposed by the health and safety assessment.

Prior to the construction of the new facilities, it is recommended that the designer and operator should prepare a written safety statement illustrated with diagrams and supported by calculations, setting down clearly the purpose and scale of the chemical plant, enumerating the various hazards associated with each stage of the plant or with the site generally and how these have been overcome. This statement will incorporate much information and advice received from the safety department as the project develops, but it is useful now that the problem should be reviewed as a whole and not piecemeal.

In considering the buildings and their location the assessor will expect to find answers to various questions relating to the safety of the site and the buildings.

(1) Has the site been flooded in the past? What would be the effect of flooding? Is there a possibility of a criticality incident? Have adequate precautions been taken?

(2) What combustible materials are used in the process or the building? Are there sufficient fire breaks and emergency exits? Are there adequate fire-fighting facilities, including hydrants?

(3) What is the maximum accident postulated for the process? What would be its effect on and off site? What health physics facilities and services exist? What emergency control points have been established?

In considering the process and the plant, the assessor will have other questions in mind.

(4) Will the workers be fully protected against radiation and contamination?

(5) It is possible to use substitute materials of smaller hazard (chemical and radioactive) than the ones proposed in the flowsheet?

(6) Is the layout conducive to effective and safe working?

(7) Has the possibility of mutual interaction between different parts of the plant leading to a hazard been fully studied and guarded against?

(8) Is the ventilation system adequate both in volume of air change, segregation of areas and height of stack? Is the filter system fully fire resistant and is there adequate provision for the safe changing of filters?

(9) Is the change-room accommodation well designed and adequate? Are the right materials used for floors, walls and ceilings? (The same question needs to be answered for the building generally.)

(10) What are the arrangements for waste disposal? Are they in accordance with the site authorisation?

(11) Is there a proposal to appoint a competent person to organise a radiation record service and health register? Are the provisions of the relevant acts (Factory, Nuclear Installations, Radioactive Substances) fully met?

(12) Is there a well-defined safety organisation with the responsibilities of each person clearly stated?

(13) Has a local liaison committee been established?

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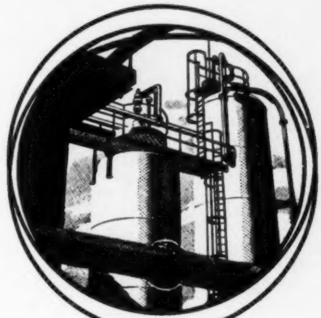
Materials of Construction for Chemical Plant



NEW METALS

By A. H. Barber*

This article on new metals forms the eighteenth in our series on 'Materials of Construction for Chemical Plant'. Previous articles have included PVC, lead, nickel, stainless steels, graphite, polyolefines, copper, timber, platinum, titanium, aluminium, reinforced plastics, cast iron, mild steel, silver, glass and ceramics. The new metals emphasised in this article are beryllium, zirconium, niobium and tantalum. Despite their high cost, they are of importance to the chemical engineer due to their excellent corrosion resistance and high strength at elevated temperatures.

IN this article on new metals immediately interesting to the chemical engineer,† special emphasis is given to beryllium, zirconium, niobium (sometimes known as columbium) and tantalum. Although these elements were isolated about a century ago, they are 'new' in the sense that they have only achieved commercial status within the last 15 years. The long delay between isolation and commercial production is attributable partly to technical difficulties but more to lack of demand. It was largely the growth of civil nuclear engineering which initiated the vast effort needed to produce beryllium, zirconium and niobium, while commercial production of tantalum was stimulated by a demand for lamp filaments and electrolytic rectifiers.

The new metals are important to the chemical engineer because they have higher strength at elevated temperatures, and better corrosion resistance, than traditional structural metals. Those which are already used, or are likely to find early use, as materials of construction in the chemical industry are shown in bold type in Table 1.

†A full account of the use of titanium for chemical plant has been given by Connolly and Watkins.[1]

Beryllium[2]

All the beryllium produced commercially is extracted from beryl, a complex beryllium aluminium silicate, which is generally converted to the oxide or hydroxide; in the two commercial processes, the oxide is converted to halide before reduction to metal. One route yields beryllium pebble by magnesium reduction of beryllium fluoride, the second beryllium flake by low-temperature electrolysis of a beryllium/sodium chloride mixture. In a typical fabrication process used in the U.K., the crude beryllium is initially consolidated by vacuum induction melting, principally as a purification process. The large as-cast grain size and the anisotropic mechanical properties of the beryllium crystal cause difficulties if ingot material is machined or wrought. Therefore, vacuum-melted ingot is usually machined to swarf, which is then ground to powder and compacted by vacuum hot pressing. The fine-grained hot-pressed compact can readily be machined, or clad in a mild-steel jacket and hot-worked by rolling, forging or extrusion. Some machined and extruded products are shown in Fig. 1. Beryllium is toxic if inhaled, but special precautions are taken during processing to discount this hazard.

Zirconium[3]

All zirconium minerals contain up to about 2% hafnium, which is almost identical to zirconium in its chemical behaviour. Hafnium-free zirconium is necessary for nuclear applications, but for chemical plant service the expense of separation can be avoided, as 2% of hafnium has no significant effect on the corrosion resistance of zirconium. Practically all the zirconium produced commercially is extracted from zirconium silicate or from zirconia. In a typical extraction process, zirconia (ZrO_2) is converted to the carbide by heating with carbon, and chlorinated at high temperature to give zirconium tetrachloride, which can be readily separated from the more volatile titanium and silicon compounds. Zirconium tetrachloride is converted to zirconium sponge by the Kroll pro-

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cess, using magnesium reduction in a helium atmosphere at about 825°C., excess magnesium or magnesium chloride being removed by vacuum distillation. Large consumable electrodes made by compacting the sponge granules are arc-melted in a vacuum furnace, complete homogeneity being achieved by remelting. Ingots weighing up to about 5,000 lb. are produced and fabricated into a complete range of wrought forms. Examples are given in Fig. 2.

Niobium[4, 5] and tantalum[4, 6]

These two elements generally occur together in combination with iron and manganese, as columbite where niobium predominates and as tantalite where tantalum predominates. The presence of tantalum is not detrimental in niobium used for chemical plant, or for high-temperature applications, but tantalum-free niobium is needed for nuclear applications. Of several methods of extraction and separation, one established method[7] is summarised as an example. The ore is converted to pure fluorides of niobium and tantalum so that they can be separately extracted from acid solutions by specific organic solvents. After separation, the fluorides are converted to oxide and reduced to the metal by heating with carbon or, preferably, sodium or magnesium. Niobium or tantalum in powder form is consolidated by vacuum sintering at about 2,300°C., followed by forging or rolling. Electron beam and vacuum arc melting are alternative methods of final consolidation. Working into wrought forms follows conventional practice, but all processes are carried out cold.

Mechanical and physical properties

Typical mechanical and physical properties are listed in Tables 2 and 3. Beryllium has low ductility, but its modulus of elasticity is unusually high for a light metal. Stronger than steel, it retains its strength at high temperatures. Zirconium has good mechanical properties at room temperature, but retains strength at elevated temperatures only if highly alloyed. Niobium and tantalum have good mechanical properties at room and elevated temperatures.

All four metals are steel-grey in appearance and, from beryllium to tantalum, there is a progressive increase in density, melting point and neutron absorption.

Corrosion resistance and uses

The free energies of formation of beryllium, zirconium, niobium and tantalum oxides indicate that they are intrinsically more reactive than metals such as gold or silver. However, at room temperature, they combine readily with oxygen to form tenacious surface films which can function as a barrier between a corrodent and the underlying reactive metal. Corrosion resistance of the new metals is summarised in Table 4, and Stern and Bishop have made a qualitative comparison of a variety of metals used for corrosive service.[8]

It must be noted that, if there is any doubt about corrosion behaviour in a specific corrodent, published data should be augmented by plant trials under realistic service conditions, which should include the use of heat transfer and the presence of impurities in the process liquor.

Beryllium

The general and galvanic behaviour of beryllium is similar to that of aluminium. Both metals are passive in concentrated nitric acid but are attacked by the dilute acid; for example, the average corrosion rate of beryllium in 10% w/w nitric acid at room temperature is about 0.05 i.p.y. (inch per year). The metal is attacked in all really aggressive media, including sulphuric and phosphoric acids, hydrochloric acid and the other halide acids in all concentrations, and dissolves readily in aqueous sodium or potassium hydroxide solutions. It is,

Table 1. Position of the new metals in the periodic table

GROUPS	0	I	II	III	IV	V	VI	VII
		H						
First short period	He	Li	**Be**	B	C	N	O	F
Second short period	Ne	Na	Mg	Al	Si	P	S	Cl

GROUPS	0	IA	IIA	IIIA	IVA	VA	VIA	VIIA	VIII			IB	IIB	IIIB	IVB	VB	VIB	VIIB
First long period	A	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br
Second long period	Kr	Rb	Sr	Y	**Zr**	**Nb**	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I
Third long period	Xe	Cs	Ba	La, etc.	Hf	**Ta**	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At
	Rn	Fr	Ra	Ac	Th	Pa	U, etc.											

New metals immediately interesting to the chemical engineer — Other metals — Non-metals

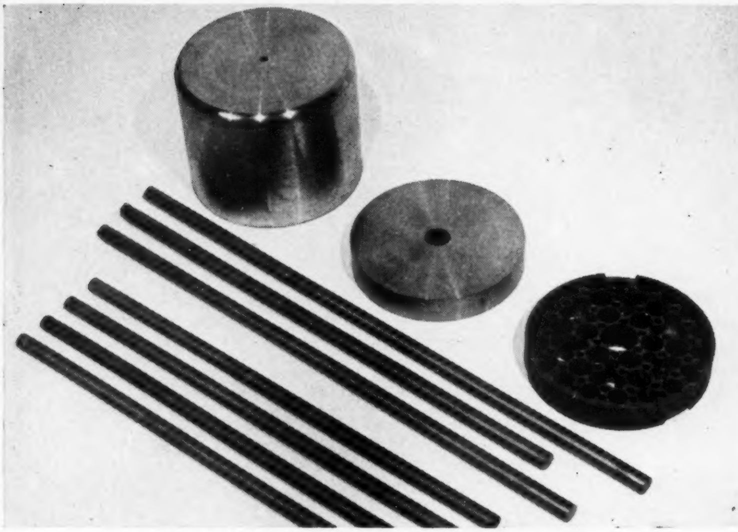

Fig. 1. Wrought and machined beryllium components

however, resistant to fairly inert gases such as carbon dioxide at about 300 p.s.i.g. and up to about 700°C., provided that the water content of the gas is not greater than, say, 150 p.p.m. The nuclear properties of beryllium, combined with its resistance to carbon dioxide, account for its principal use for fuel sheathing in gas-cooled reactors.

Beryllium has good resistance to liquid metals. It is particularly suitable for use with molten lithium and has excellent resistance to liquid sodium and sodium-potassium alloy under oxygen-free conditions, although corrosion occurs when oxygen is present. In molten aluminium, beryllium suffers intergranular attack. Beryllium is a useful alloying element, up to 2% beryllium being used to effect precipitation hardening of copper alloys. Because these alloys resist corrosion, wear and fatigue, they are widely used for scraper blades, springs and similar equipment.

Beryllium is unlikely to find general use in the chemical industry, but its remarkably high strength/weight ratio, combined with corrosion resistance similar to that of aluminium, suggests its use for certain specialised applications such as the construction of super-centrifuges.

Zirconium

The general[9] and galvanic[10] corrosion behaviour of zirconium is similar to that of titanium, although in certain media its performance is superior. Zirconium generally has excellent resistance to reducing media even if chloride ions are present, but is resistant to oxidising media only in the absence of chloride. For all practical purposes, zirconium is completely resistant to hydrochloric acid in all concentrations and at all temperatures up to the boiling point; in a non-oxidising metal chloride solution (for example, a 25% w/w solution of aluminium chloride) it is unattacked at all temperatures up to 100°C. It has good resistance to oxidising media such as solutions of nitric or chromic acid, but the effect of the presence of chloride ions is demonstrated by a corrosion rate of almost 0.5 i.p.y. for zirconium in a 25% w/w solution of ferric chloride at 35°C. Titanium, on the other hand, is generally unsatisfactory in reducing media, but has excellent resistance to oxidising environments, even in the presence of chloride.

'Borderline passivity' conditions in certain media provide a further example of differences in the corrosion behaviour of zirconium and titanium. Zirconium specimens immersed in aqua regia sometimes remain passive but are often severely corroded, while corresponding specimens of titanium are virtually unattacked. Titanium shows 'borderline passivity' in nitrogen-agitated solutions of formic acid, while zirconium is attacked at a rate of less than 0.001 i.p.y.

Zirconium is corroded by all concentrations of hydrofluoric, but only by strong solutions of phosphoric and sulphuric acid. It is resistant to concentrations of sulphuric acid up to about 70% w/w at temperatures up to the boiling point, but at higher temperatures it is severely attacked, corroding at a rate of 0.57 i.p.y. in boiling 85% w/w sulphuric acid solution. It has outstanding resistance to corrosion by hydrochloric acid; for example, in boiling 20% w/w solutions at atmospheric pressure, it corrodes at less than 0.005 i.p.y. Kuhn has described the corrosion behaviour of zirconium in hydrochloric acid at atmospheric[11] and high[12] pressures. In nitric acid, zirconium has good corrosion resistance, but in solutions containing free NO_2, pyrophoric behaviour occurs more readily with zirconium than with titanium.

The general corrosion resistance of zirconium in acid environments, bettered only by that of tantalum, is combined with outstanding resistance to solutions of alkalis and to fused alkalis (except fused potassium hydroxide). This combination enables the metal to withstand alternate exposure to acid and alkaline environments.

Certain metallurgical factors can reduce the corrosion resistance of zirconium. Slight variations in rate of corrosion are reported[11] for material having different surface finishes. Early production batches of zirconium having high carbon contents were less resistant than present-day material. Traces of impurities in a process liquor can cause increased attack, *e.g.* the

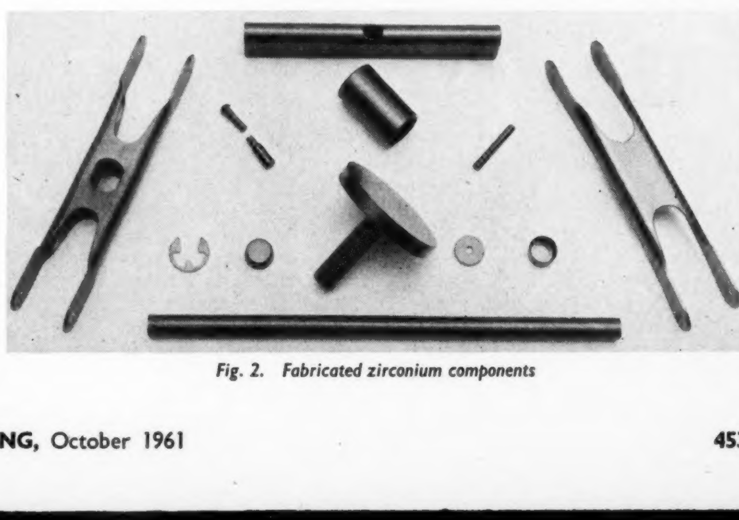

Fig. 2. Fabricated zirconium components

Table 2. Typical Mechanical Properties of the New Metals at Room Temperature

	Beryllium (fluoride-reduced pebble, vacuum cast, extruded and annealed)	*Titanium*			*Zirconium (Kroll sponge, arc melted)*	*Hafnium*	*Vanadium*	*Niobium (sintered bar)*	*Tantalum (annealed)*	*Chromium*	*Molybdenum*	*Tungsten*
		Ti 120	*Ti* 130	*Ti* 160								
U.T.S. (tons/sq.in.)	22 to 36	30 max.	30 to 40	40 to 50	27.2	22.0	28.3	17.7	30	5.4	75	100
Elongation (%)	0 to 20	25 min.	20 min.	15 min.	30	35	35	49	30	Potentially a ductile metal but small amounts of impurities promote brittleness	10 to 25	1 to 4
Hardness (D.P.N.)	200 to 250	120 to 150	150 to 180	220 to 270	140	180	165	As low as 40 depending on purity	As low as 45 depending on purity	About 1,000 falling to below 200 after annealing	260	430

Table 3. Physical Properties of the New Metals

	Beryllium	*Titanium*	*Zirconium*	*Hafnium*	*Vanadium*	*Niobium*	*Tantalum*	*Chromium*	*Molybdenum*	*Tungsten*
Atomic number	4	22	40	72	23	41	73	24	42	74
Atomic weight	9.02	47.90	91.22	178.54	50.95	92.91	180.88	52.01	95.95	183.92
Crystal structure	c.p.h. b.c.c. above 1,250°C.	c.p.h. below 882°C.; b.c.c. above 882°C.	c.p.h. up to 862 ±5°C.; above this temp., b.c.c.	c.p.h. up to 1,950 ±10°C.; above this temp., b.c.c.	b.c.c.	b.c.c.	b.c.c.		b.c.c.	b.c.c.
Melting point, °C.	1,283	1,660	1,860	2,130	1,735	2,415	2,950	1,865	2,620	3,410
Density at room temp. g./c.c.	1.85	4.5	6.505	13.36	6.02	8.6	16.6	7.19	10.2	19.3
Density at room temp. lb./cu.in.	0.066	0.163	0.235	0.485	0.22	0.31	0.61	0.26	0.37	0.69
Thermal conductivity at room temp., cal./sec.cm.°C. ..	0.36	0.04	0.04	0.056	0.09	0.13	0.13	0.215	0.346	0.476
Thermal neutron absorption cross-section: microscopic barns/atom	0.01	5.6	0.18	105	4.98	1.1	21.3	2.9	2.5	19.2
macroscopic cm.$^{-1}$ ..	0.0012	0.32	0.036	4.71	0.51	0.060	1.18	0.24	0.16	1.21
Specific heat at room temp., cal./g.°C.	0.42	0.129	0.066	0.034	0.12	0.065	0.036	0.15	0.065	0.034
Coefficient of linear expansion (25 to 100°C.) × 10^{-6}/°C.	11.5	8.5	5.4	5.9	7.8	6.86	6.5	4.4	4.9	4.0
Young's modulus at room temp., p.s.i. × 10^{-6} ..	43	16 to 18	11 to 12	14	20 to 22	15	27	42	40 to 50	50 to 60

presence of 50 p.p.m. ferric ions in a boiling concentrated solution of hydrochloric acid gave a corrosion rate of 0.002 i.p.y., roughly ten times that obtained in the absence of iron. The presence of fluoride ions can also cause increased attack.

Like beryllium, zirconium is primarily a nuclear engineering material and its main application is for fuel sheathing and other reactor components. In the chemical industry, its main use is to withstand corrosion by hydrochloric acid and other media in which the less-expensive titanium suffers attack. Zirconium valves, thermometer pockets, pump impellers and casings and immersion heater sheaths are in service in hydrochloric acid solutions.

A heat exchanger used in a hydrogen peroxide concentration process and crucibles used for caustic fusions are also made of zirconium.

Niobium and tantalum

There is no significant difference in the corrosion behaviour of these two metals at room temperature. They are almost completely resistant to corrosion by all concentrations of all acids, except hydrofluoric acid and fuming sulphuric acid. At higher tempera-

tures there is a marked decrease in the resistance of niobium, seriously restricting its application in the chemical industry. For example, tantalum remains unattacked in boiling concentrated hydrochloric acid, but niobium corrodes at about 0.004 i.p.y. Where marginal improvements in the corrosion resistance of niobium would be worth while, tantalum-rich niobium alloys may give adequate resistance without prohibitive expense.

The chemical behaviour of tantalum, which is scarcely attacked by most acids but is corroded by hot strong alkalis, is often compared with that of glass. With the exception of these alkaline environments, tantalum is resistant to both oxidising and non-oxidising media, even when appreciable quantities of chloride are present. Fluoride ions result in a marked decrease in resistance, and it is reported[13] that commercial phosphoric acid frequently contains enough hydrofluoric acid to cause serious corrosion. If phosphoric acid is to be handled at temperatures above 143°C., plant trials should be made because there is some evidence that tantalum is attacked at higher temperatures. Chlorine, bromine or iodine in liquid or vapour form do not react below 149°C. and the metal resists attack by all salts except those which hydrolyse to strong alkalis. It has good resistance to liquid metals, provided only inert gases are present.

When niobium and tantalum are heated in a hydrogen atmosphere, or exposed to cathodic processes in an acid solution, or to aggressive corrodents containing no strong oxidising agents, the metals combine with hydrogen, becoming hard and brittle. Niobium is more susceptible than tantalum. When the metals are used in chemical plant, it is important that they are insulated from direct contact with less noble metals and that they are not exposed to stray electric currents. Where hydrogen is evolved by corrosion of tantalum, it has been suggested that embrittlement could be prevented by electrochemical methods[14, 15] or by contact of tantalum with an extremely small area of platinum.[16]

When used as an anode in electrochemical processes, both niobium and tantalum form anodic films of unusual stability, the films on tantalum being the more stable. A tantalum and a lead electrode, immersed in a sulphuric acid solution, form a simple but extremely dependable rectifier, and an important use of tantalum is for small electrical capacitors with high capacity, low reverse currents and serviceability over a wide temperature range. Tantalum thinly coated with platinum has been used as a catalyst and for power-impressed anodes in electrochemical processes,[17] though this is now generally superseded by the cheaper platinised titanium, except for applications where the carrier metal must have a high breakdown voltage.

Because of its freedom from pitting attack, thin tantalum sections, typically 0.012 to 0.020 in. thick, are used for lining mild-steel vessels. Because the linings cannot be successfully welded to the steel, they are attached mechanically. Where linings are to operate at elevated temperatures, careful design may be necessary to compensate for differential expansion between vessel and lining.

Use in heat exchangers

Tantalum is eminently suitable for constructing heat exchangers. It is reported[18] that a bayonet heater 1.5 in. diam. × 6 ft. long, with a heating area of 2.36 sq.ft., will evaporate about 1 ton/hr. of 95% nitric acid, using steam at 150 p.s.i. In the concentration and recovery of sulphuric acid, severe corrosion of tantalum at elevated temperatures can be minimised by operating under reduced pressure. Tantalum bolts, fitted with PTFE gaskets, are used for the repair of perforations in glass-enamelled steel vessels. The first hydrochloric acid absorption plant fabricated in tantalum was installed in 1937, and within five years tantalum absorption units were used for 80% of the hydrochloric acid made in the U.S.[18] Tantalum has also been used for thermopockets, spinnerets, lined valves, concentric tube and shell-and-tube heat exchangers, and stem tips and seats in needle valves, the needle being hardened by oxidation. Many high-purity drugs and pharmaceutical products are handled in tantalum equipment; before the advent of titanium, the metal was used for surgical implants, emphasising its freedom from toxicity.

Unlike tantalum, niobium has not been extensively developed as a chemical engineering material, the advantages of lower density and lower price being offset by inferior corrosion resistance. There is an appreciable demand for niobium in nuclear engineering, and it is used as a 'getter' in vacuum techniques. As ferro-columbium, niobium is used in the fixation of carbon in stainless steels.

Much effort is now going into the development of niobium alloys with improved oxidation resistance at high temperatures; alloys devised as a result may well open up new concepts of high-temperature chemistry.

Titanium alloys

Because titanium is appreciably cheaper than other new metals, there is a considerable incentive to improve its resistance in media which normally attack it.[19] Impressed-voltage anodic passivation techniques are successful in many media, but are not always acceptable. However, several titanium alloys offer improved resistance to non-oxidising acids. The greatest improvements are achieved when titanium is alloyed with more noble metals, such as palladium[8] or with metals such as molybdenum[20] or zirconium.[21]

Molybdenum

Molybdenum has satisfactory resistance in many acid solutions under completely submerged conditions. It is used in the chemical industry for sieves and heat-exchanger tubes operating in hydrochloric acid, and for reboilers, steam lances, tank liners and guides for making synthetic fibres. It is used as an electrode material in the fused salt electrolysis of magnesium, and as an electrode and paddle material for glass furnaces, but it must be completely covered by glass, or thoroughly cooled, to prevent oxidation. Molybdenum and molybdenum-tungsten alloys have good resistance to liquid zinc.

Chromium

Though it has good resistance in its passive state, chromium is unlikely to find wide application in the chemical industry. Passivity is maintained by the presence of dissolved oxygen in neutral solutions, but in most acid media the presence of a strong oxidising agent is necessary. The metal is attacked by solutions containing reducing agents, halogens and sulphuric acid. Hard electro-deposits of chromium are reported to have variable corrosion behaviour.[22] Vanadium, with moderately good corrosion resistance, tungsten, which has high density and poor workability, and hafnium, chemically similar to zirconium but appreciably more expensive, are of limited interest to the chemical engineer.

Fabrication

Because of toxic hazards, fabrication of beryllium components will probably be carried out by the primary metal producers, but fabrication of zir-

TABLE 4. COMPARATIVE GENERAL CORROSION

Resistance to:		*Titanium*	*Zirconium*
Alkalis		Resistant to corrosion by dilute solutions, but attacked by hot concentrated solutions, *e.g.* virtually unattacked by boiling 10% NaOH solution, but corroded at >0.005 i.p.y. in boiling 40% NaOH	Excellent resistance to alkalis, for example, virtually unattacked by 50% NaOH solution at 100°C. Attacked by fused potassium hydroxide but resistant to fused sodium peroxide at 460°C. and fused sodium and potassium carbonate at 900°C.
Chloride solutions		Excellent resistance to aqueous solutions of metal, ammonium and rare-earth chlorides, at all concentrations and at all reasonable temperatures, with the exception of aluminium and zinc chlorides. Severe corrosion occurs in hot concentrated solutions of $AlCl_3$ and $ZnCl_2$	Generally resistant to aqueous solutions of metal, ammonium and rare-earth chlorides, although significant attack can occur in solutions of cupric and ferric chloride
High-temperature oxidation		Dissolves oxygen rapidly at about 550°C.	Similar to titanium, but oxygen diffuses more rapidly in zirconium than in titanium
Inorganic acids	Aqua regia	Virtually unattacked at room temperature. At boiling point, slightly corroded in liquid phase, but severely corroded in vapour phase	Poor resistance
	Chromic	Completely resistant at concentrations up to 50%, at temperatures to boiling point	Completely resistant at concentrations up to 10% at temperatures to boiling point
	Hydrochloric	Corrosion rates are acceptably low only in cold, dilute solutions of the pure acid*	Corrosion rates less than 0.005 i.p.y. in all concentrations at temperatures to boiling point. At elevated pressures, resistance is satisfactory up to 25% at 163°C. and up to 15% at 204°C.
	Hydrofluoric	Severely corroded	Severely corroded
	Nitric	Resistant to all concentrations up to boiling point. Unsuitable in R.F.N.A. No pyrophoric reaction provided that the NO_2 content of the 99.8% acid is less than 1%	Resistant to all concentrations up to 70%; at up to 204°C. Pyrophoric behaviour can occur in certain concentrated solutions
	Phosphoric	Significantly attacked at room temperature in concentrations greater than 30%, in the pure acid*	Significant corrosion in concentrations greater than 80% at 35°C., 60% at 60°C. and 50% at boiling point. At elevated pressures, resistance is better at 149°C. and 204°C. than at atmospheric pressure
	Sulphuric	Corroded even at room temperature in the pure acid unless concentration is below about 5%*	Resistant to dilute solutions but corroded by 75% acid at 60°C. At boiling point, rapid attack occurs at about 70% acid. At elevated pressures, rapid attack occurs at about 40% at 200°C.
Liquid metals		Good resistance to sodium, potassium and sodium-potassium alloy up to 600°C. Good resistance to molten zinc as used in the dry galvanising process	Good resistance to sodium, potassium and sodium-potassium alloy up to 600°C. and lithium up to 300°C. Presence of small quantities of oxygen in the liquid metal cause a significant increase in corrosion rate
Organic acids		Resistant to all organic acids except formic and oxalic acids. All solutions of oxalic acid cause significant attack. In formic acid solutions having concentrations greater than 10%, 'borderline passivity' conditions can occur	Resistant to organic acids, including formic and oxalic acid. Resistant to formic acid even when nitrogen-agitated
General comments		Titanium is generally unsatisfactory in reducing media, but it has excellent resistance to oxidising environments, even in the presence of chloride. Avoid use of titanium in either methanolic chloride solutions or solutions containing fluorides	Zirconium has excellent resistance to reducing media, but it is resistant to oxidising media only in the absence of chloride. Avoid use of zirconium in media containing cupric, ferric or fluoride ions

*Attack can generally be inhibited by certain alloying elements, by the presence of oxidising agents, or by the use of anodic passivation techniques.

BEHAVIOUR OF THE NEW METALS

Niobium	*Tantalum*	*Other 'new' metals*
Not generally suitable for service in alkalis. Severely corroded in hot concentrated solutions and, even in certain dilute solutions, surface embrittlement may occur	Not generally suitable for service in alkalis, but slightly more resistant than niobium	Beryllium is not resistant to attack. Molybdenum and tungsten are virtually unattacked in cold aqueous solutions of KOH and NaOH. The fused hydroxides give slow oxidation in air; oxidation is rapid in the presence of oxidising agents such as KNO_2, KNO_3, $KClO_3$ and PbO_2
	Unattacked by boiling concentrated solutions of ferric and mercuric chloride	Beryllium is not resistant to attack. Molybdenum is corroded by concentrated solutions of ferric chloride
Poor oxidation resistance at temperatures above 400°C. The oxide scale is non-protective and oxygen dissolves in the metal. Niobium does not suffer catastrophic failure by oxidation at high temperatures	Similar to niobium	Oxidation of molybdenum and tungsten is appreciable at 400 to 500°C. and rapid at 600°C. The oxides are volatile. Vanadium has poor resistance because its oxide has a low melting point. Hafnium is severely embrittled by dissolved oxygen. Chromium forms a protective scale, but there is a danger of nitrogen embrittlement
Unattacked at room temperature	Unattacked at temperatures up to 60°C.	Beryllium is passive in concentrated nitric acid, but is generally corroded by other inorganic acids. Molybdenum and tungsten: (i) corroded slowly by cold aqua regia, attacked rapidly at elevated temperatures; (ii) practically unattacked by cold hydrochloric acid; (iii) unattacked by cold or warm hydrofluoric acid; (iv) corrode slowly in cold nitric acid, but are rapidly attacked at elevated temperatures; (v) virtually unattacked by cold sulphuric acid. In warm acid, molybdenum suffers slight corrosion but tungsten remains unattacked. Vanadium is resistant to dilute solutions of reducing acids, but is attacked by all concentrations of nitric acid
	Unattacked by a 10% solution at 98°C.	
At room temperature, unattacked by 20% acid, but slightly corroded in concentrated acid. Good resistance to concentrated acid below 60°C. Corroded at about 0.004 i.p.y. in boiling concentrated acid	Unattacked in concentrated acid at temperatures up to 100°C.	
Severely corroded	Severely corroded	
Unattacked in concentrated acid at temperatures up to 100°C.	Unattacked in concentrated acid at temperatures up to 86°C.	
Virtually unattacked in 85% acid at room temperature, but corroded at 0.003 i.p.y. with embrittlement, at 100°C.	Virtually unattacked in 85% acid at 145°C., but attack occurs at elevated temperatures	
At room temperature, unattacked by dilute solutions, but corroded, with embrittlement, in concentrated acid. Corrosion rate in concentrated acid is 0.019 i.p.y. at 100°C. and 0.208 i.p.y. at 150°C.	Virtually unattacked in all concentrations at temperatures up to 200°C. Above 200°C. attack is appreciable in concentrated acid, but in 20% acid no significant attack at temperatures up to 300°C.	
Resistant up to 600°C. in Li, Na, Hg, Sn, Bi and Pb, and at temperatures well above 800°C. in Na-K alloy. Presence of small quantities of oxygen in the liquid metal cause a significant increase in corrosion rate	Similar to niobium	Beryllium—good resistance to mercury up to 300°C. Molybdenum and tungsten—similar to niobium
May be embrittled, even at room temperature	Excellent resistance to all concentrations of acetic acid at temperatures up to 390°C., but significantly attacked by a saturated solution of oxalic acid at 96°C.	
Similar behaviour to tantalum at room temperature, but significantly less resistant than tantalum at elevated temperatures	Resistant to both oxidising and non-oxidising media, even in the presence of appreciable quantities of chloride. Embrittlement may be caused by either stray-current effects or hydrogen generated in corrosion processes. Avoid exposure to either strong alkalis or fluorides	

NOTE.—Concentrations are expressed as percentage by weight. Corrosion rates are expressed as average penetration in inches per year (i.p.y.). Results refer to atmospheric pressures, unless otherwise stated.

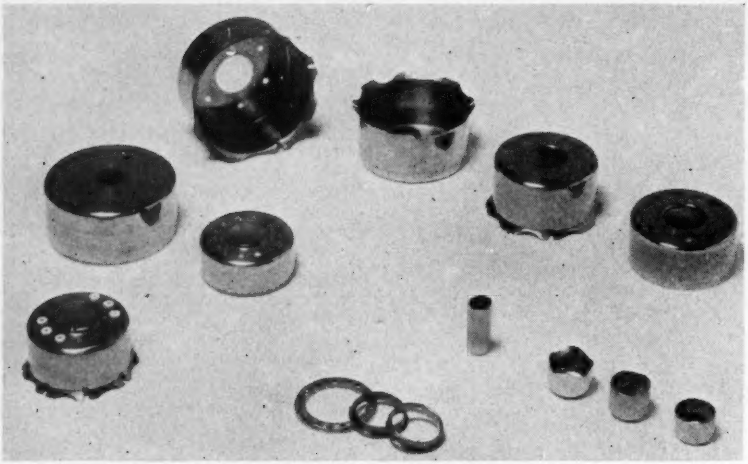

Fig. 3. Niobium, tantalum and molybdenum pressings

conium, niobium and tantalum is reasonably straightforward.

Special techniques are necessary to overcome difficulties caused by their high melting points, their reactivity with most gases at elevated temperatures, and the use of thin sections. Sprayed coatings cannot normally be used instead of thin sheet linings, because porosity in the coating may cause attack on the underlying metal.

For fusion welding, it is necessary to adopt the inert-gas shielded tungsten arc process, using argon or helium as the protective atmosphere; without this protection, the metals become hard, and often brittle, in the region of the joint.

Dry box techniques are extensively used, while for larger components and *in situ* welds, the argon-arc process is adopted, argon being supplied to the upper side of the weld bead, the back of the weld and other heated surfaces. Welds are strong and ductile and, because contamination can be kept within negligible limits, their corrosion resistance is generally the same as that of the parent sheet.

For niobium and tantalum sheet as thin as 0.01 to 0.15 in., resistance welding is normally used; argon-arc techniques are only satisfactory if the arc is automatically stabilised. Spot welding in air is practicable if the timing is held to one cycle, but for longer cycles, or for seam welding, the weld is made under water or carbon tetrachloride.

The new metals cannot be welded to stainless or carbon steels because brittle intermetallic compounds are formed, and zirconium should not be welded to titanium because the weld is not resistant to certain corrodents.

Annealed commercially pure zirconium, niobium and tantalum can readily be formed into complex shapes. The formability of zirconium is similar to that of quarter-hard austenitic stainless steel, and is improved by heating to about 300°C. As low a temperature as possible should be used for hot working because of the rapid diffusion of oxygen and nitrogen.

Niobium and tantalum are soft and ductile metals which, because of their reactivity with atmospheric gases, must on no account be heated in air before forming. They will accept cold working reductions of over 90% before annealing becomes necessary. At this stage, treatment for 1 hr. at 1,300° to 1,400°C. is satisfactory, but it must be done in an inert gas, or preferably in a high vacuum at pressures below 1×10^{-3} mm. of mercury. Niobium and tantalum are easily formed by metal spinning and deep drawing techniques (Fig. 3) and they do not spring back when stamped or forged.

Machining is governed by a tendency to gall or seize. High-speed steel tools are used, but overheating of the work and tool should be avoided by using low speeds, generous clearances and sharp tools. Production of fine zirconium turnings should be avoided as they present a fire hazard, particularly when moist; machines must be kept free from accumulated swarf and turnings destroyed by burning in the open air.

Economic considerations

It is difficult to give a realistic indication of the cost of wrought beryllium. In sheet form, zirconium costs about £8/lb. (roughly twice the price of titanium), while niobium and tantalum each cost about £20/lb. Thus, 1 sq.ft. of 0.036 in. of material costs about £4 in titanium, nearly £10 in zirconium, roughly £32 in niobium and just over £63 in tantalum.

These costs must be assessed against the many advantages associated with the use of new metals. They generally require no downtime for repairs or maintenance and, because they require no corrosion allowance, very thin sections can be used. They withstand corrodents which could not be tolerated by traditional materials and are generally unaffected by changes in operating conditions. They maintain chemical contamination at a low level, thereby retaining the efficiency of catalytic processes, and they permit increased throughput or shorter routes to purer products.

While the new metals will probably become less costly with increasing demand, their initial cost will always challenge the chemical engineer to take full advantage of their properties, rather than use them only as direct replacements for traditional materials. They commend themselves strongly to the chemical engineer faced with 'trouble spots' in existing plant, or with the need to design equipment capable of withstanding increasingly severe operating conditions.

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FILTRATION

By H. K. Suttle,* M.I.Chem.E., F.R.I.C., M.Inst.F.

This review is concerned with progress in the unit operation of filtration since the previously published review in February 1960. There has been a considerable re-examination of fundamental concepts used, such as filtration resistance and filterability. Very little work is reported on scale-up and most recent developments are still concerned with new filter media which now include fabrics, ceramics, metals, plastics and glass. It is particularly interesting to note the increasing application of filtration for waste gas cleaning. Altogether, 44 references are cited.

No book has been noticed which is concerned especially with filtration, although general texts on chemical engineering continue to be published. The book by M. G. Larian,[1] published late in 1959 in Great Britain, is an excellent work written in an attractive, flowing style, although somewhat elementary in character. There is a clear exposition of the principles of filtration together with useful worked examples. A somewhat more advanced text is presented by A. S. Foust *et al.*,[2] arranged in the modern conception of transfer processes. Filtration, which is studied within the section concerned with phase separation, commences with a description of the packed bed (sand type) filter. The various types of units —all American—are described clearly. General filter calculations are based on the Kojeny-Carman equation, and the procedure suggested for materials which yield compressible cakes is based largely on the work of Grace.[3] The final topic is the mode of calculation for centrifugal-filtration processes. The section is well documented with 48 references. The same volume contains a useful appendix devoted to particle-size measurement and distribution, the significance of the conception of sphericity and a short section on bed porosity. Engineers concerned with process economics will find useful calculation methods and guides to economic factors in a work by J. Happel,[4] although the filtration process is not specially treated.

Fundamental concepts

A previous review[5] noted the work of Hertzberg and Mountfort[6], concerned with a criterion for the prediction of the filterability of a slurry. It was remarked that the authors indicated the special features in the design of a filter station. The specific resistance of the filter cake was taken as being independent of the pressure. It has since been observed[7] that this particular condition is not necessary, the design method being valid for both compressible and incompressible cakes so long as the specific resistance of the filter cake is measured at the final pressure conditions attained in the filter unit. The restriction that the specific resistance must remain constant at a constant pressure and not change with time at a constant pressure, is important with cakes which tend to be plastic in nature. The observations of these authors would appear to represent a distinct advance in design technique.

The fourth contribution on the fundamentals of filtration, by Prof. Tiller, with, at this time, H. R. Cooper,[8] has appeared. The significance of porosity with special reference to constant-pressure filtration is considered in the broadest fashion, and demonstrates that several simplifying assumptions often used as a basis for establishing the filtration equation may be in error. After discussing the pressure at the medium relative to the resistance of the deposited cake, the general problem of resistance to filtration is considered. Early work assumed that the specific resistance could be considered constant throughout the process and that a plot of filtrate volume against time of filtration would always yield a parabolic curve. Indeed, if such a curve were not obtained, then it would be desirable to consider possible errors of experiment. This, of course, remains true for many common cases, but variation in specific resistance may be such as to cause 'a noticeable deviation in the parabolic relationship', particularly over small intervals of time. The significance is that lengthy test runs are necessary in order that confidence in the results may be secured.

The porosity of the cake varies not only with the cake thickness, but also with the time during which it is submitted to pressure. The authors have shown that a function showing porosity in relation to cake thickness can take widely differing forms, indicating rapid porosity changes either at the surface or at the medium. Thus, no generalisations are possible as to the average value of the rate of flow of liquor within the cake. Recognition of these features has led to modifications of the conventional equations and new partial differential equations are presented and discussed for flow through compressible cakes, in which, of course, the flow of liquor will vary according to the thickness of the

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deposited cake. The numerical example discussed is based on the work of H. P. Grace.[3]

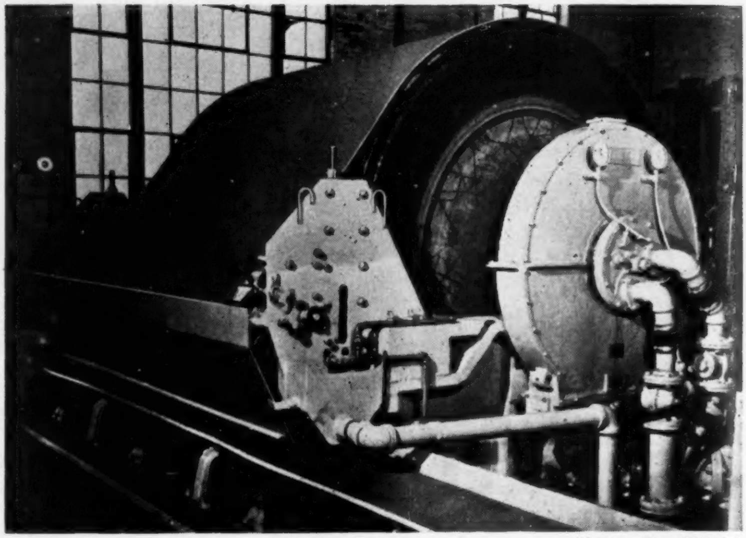
M. T. Kuo[9] has set up a mathematical model for the washing of a filter cake on the assumption that the filtrate has been forced out of the interstices of the cake prior to the washing cycle. If the wash liquor flows through the pore spaces in slug flow, then there will be a continuous mass-transfer process from the pore surfaces of the solid, where a boundary film of filtrate may be supposed to exist. Differential equations are derived, on this basis, which are shown to be of the simple form studied by S. Goldstein[10] in connection with ion-exchange problems in fixed beds. These equations may be solved explicitly, and their solutions are presented in the form of useful performance charts. Good comparisons result when the data of F. H. Rhodes[11] are contrasted with a solution by the present method.

A valuable record of the experimental procedures designed to test the validity of theoretical conceptions is contained in a paper by Valleroy and Maloney.[12] *Lucite* spheres (*Lucite* 4F moulding powder) were used as the solids, which were made into a slurry with deaerated water containing 0.05% by weight of a wetting agent (*Dreft*). A permeability cell, a vacuum filter and a horizontal centrifuge were used in the tests. Full details are given. The authors introduce their work by a consideration of the work of Grace,[3] Storrow and co-workers[13] and Maloney.[14] Their results are compared with those predicted from the Kojeny-Carman equation. Thus the conditions arranged are those associated with a bed of incompressible spheres, and it is said that these are the first known experimental data for this condition. The specific resistances agreed amongst themselves within 20% at the same pressure drop, and within 3% at the same cake porosity.

A notice occurs of an article by N. U. Koida[15] (in Russian) of the application of the principle of similarity to the filtration of liquids. Scale-up processes are particularly troublesome in filtration.

A valuable paper by Weisman and Efferding[16] is concerned with the dimensional analysis of the problem of sustaining the suspension of slurries by mechanical mixers and the correlation with experimental data.

The late Prof. White[17] evolved a useful graphical method for the scale-up in constant-rate filtration, based



[Courtesy: Eimco (G.B.) Ltd.

Fig. 1. ' EimcoBelt ' filter

upon the results of a test experiment. The present account is published by his friend, S. C. Hyman.

The control of solutions in order to assist the filtration process is a problem encountered in most industries. C. W. Davis[18] suggests that clarification of raw sugar liquors can be assisted by adjusting the phosphate content of the liquors to approximately 150 p.p.m. (as phosphorus) and the lime added in the form of saccharate in an efficient mixing device. The *p*H should be automatically controlled. In this manner, it is suggested, less suspended matter will be carried forward to the filters. Fig. 1 shows a view of an *EimcoBelt* filter suitable for direct filtration in the sugar industry.

Particle size is always a matter for consideration by the filtration engineer and, amongst the large number of papers appearing in recent times, the following has been chosen for comment. Slesser and Deans[19] have described a comparatively simple unit for this determination which is a modification of that described by D. Werner.[20] The sedimentation tube is 2.5 cm. diam. and 130 cm. long and is provided with a mixing chamber. The whole is water jacketed. ' Sedimenting concentrations down to one part in 10,000 give measurable deposits '. Using this apparatus, the mean particle size may be evaluated to within ±2%.

Filter media and filter aids

An article by J. P. Kovacs[21] makes the assertion that '. . . the area where progress has been greatest (in the last few years) is not so much in filters themselves as in filter media '. This is a good account for reference purposes. The author describes the nature of highly alloyed metals for a variety of purposes, including the handling of radioactive materials. Metal screens and strainers can now be made which are capable of removing particles down to several thousandths of an inch in size, but the newer porous metal media can remove particles as small as one or two microns (10^{-6} m.). Other materials considered are impregnated cellulose media (usually incorporating a phenolic resin); woven-wire screens of stainless steels or *Monel*[8]; fused porous metals (sinter); glass fibres; and ceramics. *Amfab* is the name given to a filter-fabric consisting of woven-glass mesh impregnated with *Teflon* or *Sylkyd* resins.[22] It is said to have a high filtration rate with easy removal of the cake. The material is manufactured to a closely controlled porosity of 1 to 75 microns and is resistant to heat and chemicals. It has a high tensile strength and a high burst strength. The materials of construction for filters are noted elsewhere,[23] and among the new fibres discussed is a modification of acetate yarn used for oil and air-conditioner filters.

The search for the perfect filter medium for the cleaning of gases and gaseous effluents continues. An article by C. S. Croman[24] describes a glass cloth which may be used at gas temperatures as high as 500° to 600°F. Glass cloth is flame treated to remove starches and sizing and is then silicone

impregnated. The resulting product is an extremely soft, flexible, smooth material which is water repellent and far more resistant to mild alkalis and acids than untreated glass fabric. It is about three times as costly as cotton fabric for the same duty, which may be compared with *Orlon* and nylon at two and a half times the unit cost. According to particle size and cloth weave, with removal efficiencies of 98 to 99.9%, pressure drops of 2.5 to 4.0 in. water are common. A general article[25] dealing with dust control has been published which describes a variety of units, including filters.

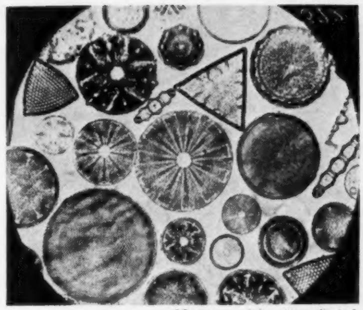
Where filter fabrics are used for the removal of aerosols, it is desirable to have some means of estimating their efficiency. Pasceri and Friedlander[26] suggest this may be done by assuming the deposition of particles of finite diameter. Theoretical expressions are derived and correlation is also made with data from the literature. An apparatus is described by Skrebowski and Sutton[27] for testing filter fabrics using a radioactive KH_2PO_4, as 0.01% in aqueous solution, and converted into an aerosol. Particles having a diameter less than 1 micron result.

A variety of filter aids[28] are now available for filtration operations which are unusually difficult, as, for example, in the manufacture of antibiotics.[29] Indeed, T. M. Jackson[30] remarks, '... The technology of filter aid filtration ... is not so highly advanced as most other unit operations in chemical engineering', and that empirical data are still required by conducting actual filter operations. The article by this author describes the properties of the following materials in detail, namely diatomite, see Fig. 2 (primarily inert silica, processed from fossilised diatoms); perlite (prepared from expanded perlitic rock, and being chiefly aluminium silicate), see Fig. 3; cellulose (a processed material used in so-called pulp filters); asbestos fibres (which form a paper-like cake); carbon (the non-activated carbons); mixtures of asbestos-diatomite and of asbestos-cellulose. The method of pre-coating is described for batch and continuous rotary filters, the amount used varying from 3 to 12 lb./100 sq.ft. of filter area according to the type of unit.

Waste gases and fume control

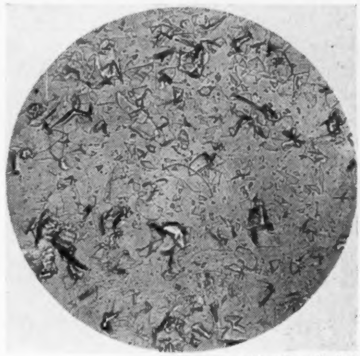
An article by R. J. Hamilton[31] shows the nature of the problem with extreme clarity. This is a contribution from the Mining Research Establishment and deals with the control of airborne dust. Discussions emphasise falling speeds, stopping distances of particles, dust suppression and control. Examples are, a minimum inward flow rate of 50 ft./min. for a local exhaust ventilation system to a minimum conveying air speed of 1,200 ft./min. for sawdust or 3,000 ft./min. for metal and mineral particles. The cleaning of air is discussed from the aspects of bag filters and electrostatic precipitators. Five authoritative books are suggested for further reading. The emission of grit at coal carbonisation plants has long been recognised as a most serious nuisance. Filtration processes are impossible, but the interested reader will find the problem graphically described in a paper (Harris *et al.*[32]) when no less than 1 million B.T.U./ton are removed in the quenching of 13-ton charges of coke.

The intensification of production in the heavy chemicals industry brings with it, almost invariably, the problem of waste gas treatment. W. Strauss[33] has discussed the matter in relation to the operation of open-hearth steel furnaces, where the increasing use of oxygen in the manufacture of steel has brought about a further aggravation of fume emission. The gases from a 200-ton open-hearth furnace are at approximately 750°C., and a production rate, at this temperature, of some 100,000 cu.ft./min. This gas rate corresponds to 2,500 cu.ft./min. at normal temperatures and for this condition is found to contain some 0.17 gr./cu.ft. of particulate fume, consisting of about 50% mixed iron oxides. Variations in these quantities occur according to the operation procedure. The size variation of the particles is probably in the range 0.1 to 1.0 micron. Pilot-plant experiments on the gases cooled to 140°C. showed virtually 100% efficiency of removal on filtration through filter bags constructed of *Orlon*. *Terylene* bags failed rapidly and the life of the *Orlon*



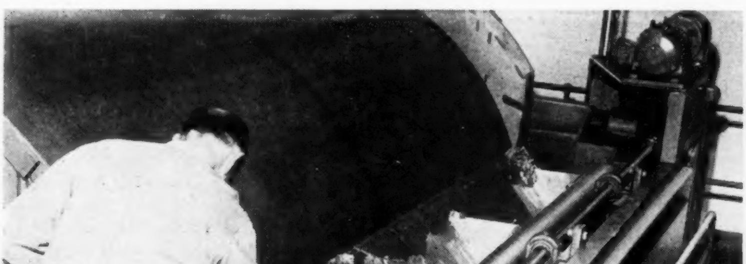
[Courtesy: Johns-Manville Ltd.

Fig. 2. Photomicrograph illustrating different diatomite forms of celite filter-aid material



[Courtesy: Johns-Manville Ltd.

Fig. 3. Photomicrograph of an expanded perlite filter-aid material



[Courtesy: Davey, Paxman & Co. Ltd.

Fig. 4. View of pre-coat shave-off knife

was extended by increasing the gas temperature to 160°C., a temperature higher than the dewpoint at which acids may be expected to deposit. Other processes discussed include cyclones (found to have too high a pressure drop), electrostatic precipitation (found to possess several drawbacks) and agglomeration by magnetic fields. To this valuable paper are appended 14 references.

The control and recovery of fume in the lead industry is the contribution by C. A. Bainbridge,[34] who shows that lead oxide is emitted from lead smelting furnaces in the size range 0.01 to 0.1 micron, agglomerating on cooling to clumps of 0.5 to 5 microns in size. This particular size material is highly toxic and can produce lead poisoning by direct absorption into the blood stream. Fabric bag filters are commonly used, and the example discussed is constructed of woollen cloth. The furnace gases leave at a temperature of about 1,200°C. at the rate of 4,850 cu.ft./min. (900 cu.ft./min. at normal temperatures), and it is necessary to cool down below the safe working temperature of the cloth, namely 100°C. This cooling process involves special design considerations by reason of the 'sticky', strongly adherent nature of the lead fume. The article describes the operation of a six-compartment *Pontifex* filter with a total filtering area of 2,496 sq. ft., which is completely instrumented.

The type of filter found to be most useful for the conditions encountered in the treatment of the gaseous effluent from an air-cooled reactor, is the subject of an article by I. A. Mossop.[35] Stack velocities are said to approach 2,000 ft./min. with a discharge of 1 ton/sec. of gas. This gas is at a high temperature containing dust which varies in size and quantity over wide limits and, moreover, the allowable pressure drop is a few millimetres of mercury only. The solids content consists of concrete, graphite or metal dust, with 'particulate matter containing fission products emanating from exposed uranium'. It is well known that such dust emission to the surrounding atmosphere must be very small indeed and, in addition, the handling of the material presents a special problem in itself. Economically, the filter installed should be cheap, so that it may be discarded after use. Sieve-type impaction filters are used, provided with an adherent film of oil. The oil preparation consists of silicone oil emulsified with 40% by weight of water using *Lissapol NDE* as the emulsifying agent. Glass-fibre mats of various types are discussed, in which the glass fibres have a random arrangement. Details of performance are given.

Earlier review articles have noted the use of filtering equipment in chemical processing, and their use is particularly emphasised in an article by Angelo and Kieber[36] dealing with the manufacture of citric acid. This material is made by a deep fermentation process from a convenient source of glucose—blackstrap molasses is suggested—by a strain of *aspergillus niger*. The mycelium waste from the fermentor is filtered off by means of a rotary drum string filter, made of stainless steel. The calcium citrate is purified and removed in the same manner. Citric acid is formed by the hydrolysis of the citrate, using sulphuric acid, and the calcium sulphate formed is removed in the same type of filtering unit. Decolorisation of the liquor is necessary and this is accomplished with an activated carbon, which is filtered off in a leaf-type filter. Fig. 4 shows a pre-coat shave-off knife fitted to a 300-sq.ft. stainless-steel filter in the works of an antibiotics manufacturer.

General equipment and control

The adaptation of batch-type filters to automatic operation is an attractive proposition. The re-slurrying of the solid matter after the filter cycle is the subject of an article by R. T. Grimm.[37] The methods outlined include an oscillating sluice, a sluice with air sparge, in addition to back-washing, the rotating leaf and wire cutter. Failures in filtration processes are discussed in a section of an article by Troyan,[38] particularly emphasised being the problem of sustaining operating pressure and the maintenance of plant operation to retain the desired crystal size. Details of construction are given, in a short article by Leonard,[39] of an emergency filter-cloth support made of wood which was arranged as a temporary replacement for a porous silica block support, normally used on an 8-sq.ft. vacuum Nutsche filter.

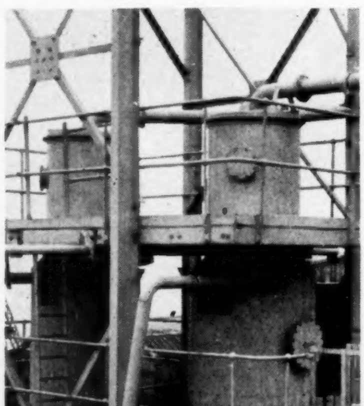


Fig. 5. Full view of two Bivac 'G' type units

The cost of plate and frame filters is given by J. L. Hutton, Jr.[40] for construction in cast iron, PVC-coated iron, CF-8M stainless steel, wood, aluminium and ⅛-in. rubber-covered iron.

The information is presented as purchase cost versus filter area, and is said to be within 10 to 15% of actual f.o.b. costs as at May 1960. This is a valuable contribution and replaces data for this particular unit presented as a nomograph at an earlier date. The author is a member of the staff of the manufacturing concern of T. Shriver & Co.

K. Heinrich[41] discusses a unit to which the name *Immedium* filter has been given. It is essentially an upward-flow operation where the unit has a drainage system, located at the upper very fine filter layer, for removing the filtrate. High capacity and a greatly increased rate of filtration are claimed.

Information is at hand on a tray-belt filter which operates on the simple principle of the Buchner funnel filter, evolved by the Swedish firm of A.B. Kemiska Patenter with British licensees[42].

The efficiency of continuous rotary drum filtration is considered by H. R. Cooper,[43] who, after considerations of various procedures, suggests a modified expression for this purpose. Excellent examples are discussed relating to the filtration of a chalk slurry, a reduced copper slurry and a micro-crystalline wax.

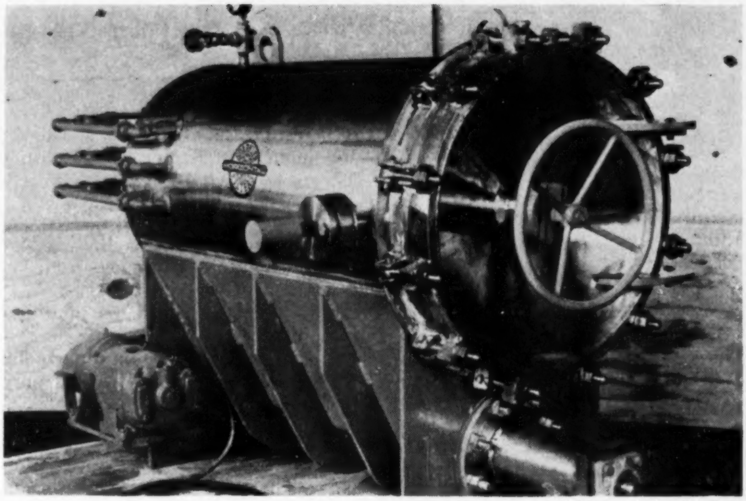
Attention is drawn, finally, to the papers by H. Birchall and D. S. Binsted[44] on work study in project planning of a chemical process, in the belief that it will be of interest to practising filtration engineers.

Powder handling techniques demand dustless conveying, and a new system devised by Bivac Air Co. Ltd. gives rapid handling—from 5 cwt.

to 12 tons/hr.—of fine chemicals in the micron or sub-micron range.

In one type of plant the powder to be conveyed is dropped from a storage hopper through a rotary or similar valve into the pipeline through which a high-speed stream of air passes, conveying the material to the type of combined filters and storage hoppers shown in Fig. 5. In these units the conveyed material is separated out and dropped by gravity into a further process or storage hopper.

Fig. 6 shows a view of the *Sparkler* model HRC filter which combines cake stability and precoating advantages of the horizontal-plate filter together with automatic dry cake discharge, without opening the filter.



[Courtesy: L. A. Mitchell Ltd.

Fig. 6. 'Sparkler' model HRC filter

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Vacuum symposium

The Institute of Physics will be holding a one-day symposium on 'Some Aspects of Vacuum Science and Technology' at Imperial College of Science and Technology, London, on January 5, 1962. The scope of the symposium will be (*a*) continuously exhausted bakeable vacuum apparatus for pressures below 10^{-9} mm. of mercury and (*b*) the controlled deposition of evaporated film.

Further details will be available at the end of October 1961 from the administration assistant, Institute of Physics and the Physical Society, 47 Belgrave Square, London, S.W.1.

Pipes and Pipework

A special feature on pipes and pipework appears in the October issue of **Manufacturing Chemist.** W. H. Komer has contributed an article on Piping Up of Chemical Plants and other articles include: How Big Should a Storage Tank Be? by A. Battersby, and Sulphonation of Detergent Materials with Converter Gas, by A. Davidsohn.

The following articles appearing in our associate journals may be of interest to readers of CPE.

Petroleum—Refrigeration in the Petroleum Industry. The Russian Petroleum Industry, by Vasily Sukhanov.

Paint Manufacture—Metal Finishes Based on Vinyl Organosols, by G. E. C. Mercer. A New Silicone Paint System, by P. A. Griffin.

Food Manufacture — Review of Mechanical Handling Equipment.

Specimen copies of these journals and subscription forms are available from the Circulation Manager, Leonard Hill House, Eden Street, London, N.W.1.

CPE DIARY

OCTOBER 10 TO 21 **Industrial Efficiency and Safety Exhibition,** organised by Provincial Exhibitions Ltd., to be held at the City Hall, Manchester.

OCTOBER 17 TO 19 **Engineering Industries Association Engineering Display** to be held at the New Horticultural Hall, London. Details from Secretary, 9 Seymour Street, London, W.1.

OCTOBER 19 The first annual lecture given by the Council of the Society of Instrument Technology, to be called the **Thomson lecture** and given by Sir G. Thomson, F.R.S., to be held at the Royal Institution. Details from the Secretary, 20 Queen Anne Street, London, W.1.

OCTOBER 19 TO 20 Symposium on **Scale-up and Pilot Plants,** organised by Graduates and Students Section, Institution of Chemical Engineers, at Royal Overseas League, St. James's Street, London, W.1.

OCTOBER 19 TO 30 First European symposium on **Food Technology** to be held at Frankfurt. It will be the 34th meeting of the European Federation of Chemical Engineers. Further information from Dechema, P.O.B. 7746, Frankfurt (Main) 7.

NOVEMBER ISSUE OF CPE

Some articles in next month's issue of particular interest to our readers are:

Calcium Reactor Vessels
By A. Knight

Fabrication of Stainless-steel Pressure Vessels in Sweden
By E. Jonnerby

CPE Unit Operations Review—Mixing
By G. J. Jameson

Development and Planning of Chemical Processes.
By Prof. K. Schoenemann

Materials of Construction for Chemical Plant—Rubber
By I. L. Hepner

Personal Paragraphs

★ **Mr. G. H. Duffield** has been appointed a director of Lightnin Mixers Ltd. He is already a director of Stockdale Engineering Ltd.

★ Following a recent illness, **Mr. D. R. Mackie** has resigned from his position as managing director of Monsanto Chemicals Ltd. He continues as a member of the board. He will be succeeded as managing director by **Mr. J. C. Garrells, Jnr.,** deputy managing director.

★ **Mr. T. C. Hale,** joint managing director of the Cape Asbestos Co. Ltd., has died. **Mr. L. C. Dawson** and **Dr. R. Gaze** have been appointed executive directors to the company's board.

★ **Mr. S. J. Reason,** until recently the senior technical representative with Nordac Ltd., has been appointed manager of the new Chemical & Nuclear Plant Division of Uddeholm Ltd.

Mr. S. J. Reason

Mr. F. W. Stokes

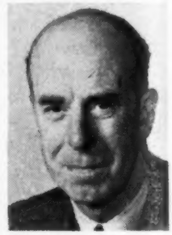
★ **Mr. F. W. Stokes** has been appointed managing director of Powell Duffryn Carbon Products Ltd. He joined the company as works manager in 1950 and was made general manager in 1960.

★ The new president of the Federation of British Rubber and Allied Manufacturers is **Mr. C. H. M. Baker,** a director of the Firestone Tyre & Rubber Co. Ltd.

Vice-presidents for 1961-62 are **Mr. D. E. Cameron,** chairman and managing director of the B.B. Chemical Co. Ltd. and **Mr. D. D. Marshall,** managing director of the Greengate & Irwell Rubber Co. Ltd.

★ **Mr. T. Carlile** has been appointed general manager of Renfrew, Dalmuir and Dumbarton works of Babcock & Wilcox Ltd. on the retirement of **Mr. D. D. Cruickshank,** C.B.E.

Mr. W. J. V. Ward



Dr. W. C. d'Leny

★ **Mr. W. J. V. Ward,** chairman of the Billingham Division, I.C.I. Ltd., died recently. He had been chairman of that division since February 1955. He is succeeded by **Dr. W. C. d'Leny,** who is at present Billingham Division joint managing director (technical).

★ In accordance with the terms of the C.J.B. scholarship scheme, administered jointly by the Institution of Chemical Engineers and Constructors John Brown Ltd., a research scholarship has recently been awarded to **Mr. A. C. Evans** of the Department of Chemical Engineering, University of Leeds.

The purpose of the scholarship is to encourage research in chemical engineering and, in particular, in chemical plant design.

★ The appointment is announced of **Mr. B. C. Aldis** as deputy general manager of the British Plastics Federation. One of his main responsibilities will be to ensure that the membership of the Federation is fully representative of this rapidly expanding industry.

★ **Mr. D. F. Campbell,** chairman of Davy-Ashmore Ltd., has announced his intention to retire from the board. **Mr. M. A. Fiennes** will succeed Mr. Campbell as chairman and **Mr. L. H. Downs** will become vice-chairman.

★ **Mr. A. H. Campbell,** who is a director of Hilger & Watts Ltd., has been appointed joint managing director with **Mr. G. A. Whipple.**

The material of construction for chemical plant which will be discussed in next month's issue of CHEMICAL & PROCESS ENGINEERING will be

RUBBER

What's New

in Plant • Equipment • Materials • Processes

CPE reference numbers are appended to all items appearing in these pages to make it easy for readers to obtain quickly, and free of charge, full details of any equipment, machinery, materials, processes, etc., in which they are interested. Simply fill in the top postcard attached, giving the appropriate reference number(s), and post it.

Computing system

At the Electronic Computer Exhibition, Panellit Ltd. demonstrated their '609' industrial information and computing system. The '609' is already in on-line operation in chemical plants, oil refineries, nuclear and conventional power stations and steelworks.

It scans continuously measurements received in the form of electrical signals from up to 1,000 or more points, and checks that these are at the required levels. It provides warning of any dangerous conditions or variations in efficiency of operation. The system produces a printed record of conditions throughout the plant at regular intervals. It calculates the efficiency of the operation of selected sections of the plant, or of the plant as a whole. This same information can also be used for the direct automatic control of the plant.

The central processing unit of the '609' is the Elliott 803 general-purpose computer. **CPE 1734**

Titanium discharge centrifuge

Sharples Metallurgical Division have now completed the development work on a P-600 *Super-D-Canter* with contact parts made of titanium. The *Super-D-Canter* is a horizontal, solid-bowl scroll discharge centrifuge and the titanium version is similar in appearance and general specification to the well-known standard P-600 model.

This new model is now available as a production unit. **CPE 1735**

Liquid oxygen packaged units

Centrepiece of the British Oxygen Aviation Services exhibit at Farnborough this year was the *Argosy Lox* system test rig. The rig demonstrates new 25-litre liquid oxygen packaged units. The 25-l. converter weighs 110 lb. when full—a quarter the weight of its gaseous counterpart—and takes up only a quarter of the space. Maximum loss rate through evaporation is less than 6% in 24 hr.

Other items included are a M.R.C.S. 150 slope-controlled rectifier, a new range of rectifier welding sets for argon arc welding and a composite argon arc welding set. **CPE 1736**

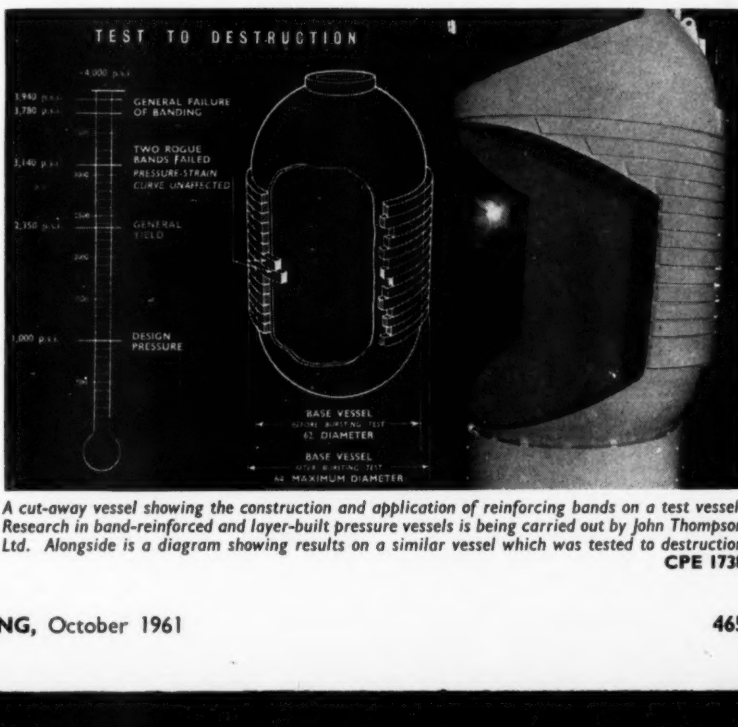
Collapsible tanks

Lightweight tanks made of synthetic rubber and nylon, which can be filled and dismantled in a few minutes, are solving the water supply problems for companies operating in the Sahara desert. They are easy to transport and designed to preserve drinking or industrial water fresh, cold and hygienic over long periods in even the hottest temperatures.

The tank walls are made of a neoprene/nylon sandwich in five layers with a coating of aluminium-pigmented *Hypalon* synthetic rubber paint sprayed on the surface. Filling and draining the tanks is done by means of two valves with firehose-type connections. Inside there are special partitions to prevent the displacement of the water during transport. The containers range in capacity from 500 to 30,000 litres of liquid and are easily set up and can be rolled up into a small pack for storage. **CPE 1737**

Industrial nylon

Polypenco Ltd. have developed a nylon called *Polypenco* MC nylon, having high tensile and dielectric strength and high heat distortion temperatures. It can be obtained from 1 lb. in weight upwards and can be produced according to manufacturers' requirements. Quantities of large moulded items can be economically produced with no material waste.

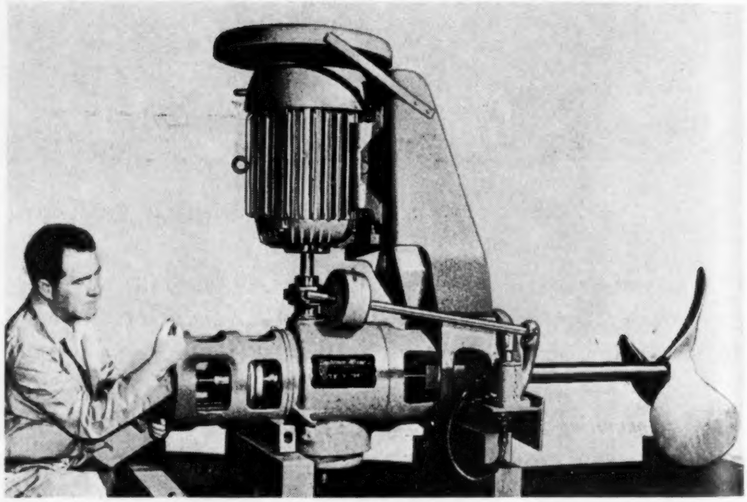


A cut-away vessel showing the construction and application of reinforcing bands on a test vessel. Research in band-reinforced and layer-built pressure vessels is being carried out by John Thompson Ltd. Alongside is a diagram showing results on a similar vessel which was tested to destruction
CPE 1738

Some applications already in hand consist of star wheels and worm screws for the bottling industry, slipper block bearings for the steel industry and massive gears for rubber mills. The availability of large sizes, a non-abrasive, corrosion-resistant quality and the fact that no hardening or tempering is required to give maximum wear life, make the nylon suitable for many heavy industrial bearing and roller applications. **CPE 1739**

Side-entering mixers

Innovations in side-entering mixer technology applied to fluid agitation in process industries have been incorporated in the new *Lightnin NSE* mixer range announced by Lightnin Mixers Ltd. The new range of models achieves a greater flow of blending capacity while installation and operating costs are reduced. These are three basic sizes of applications ranging from 1 to 50 h.p., compared to the previous limit of 25 h.p. The addition of larger units to the side-entering range, as well as increased flow of these mixers, allow, for example, a single 50-h.p. *Hi-Flo* side-entering mixer to do the job of three conventional 25-h.p. units. Multiple-unit installations are thereby often eliminated. **CPE 1740**



Checking the operation of the patented tank shut-off device on one of the new 'Lightnin' NSE side-entry mixers

Dust-control processes

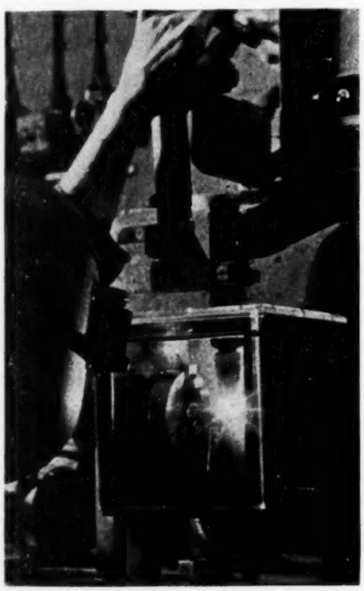
At the Heating, Ventilating and Air Conditioning Exhibition, Ambuco Ltd. showed working demonstrations of two dust-control processes.

The first concerned Ambuco venturi scrubbers, which are made under licence from Waagner-Biro of Austria. The technique used, which can be applied to a wide variety of industrial processes ranging from metal refining to chemical manufacture, ensures a high efficiency for the removal of entrained solids in the particle size range 5 to 0.01 micron. The other demonstration showed the operation of Ambuco guaranteed efficiency cyclones. These have a 'shave-off' port to ensure efficiency. **CPE 1741**

Resin-bonded fabric bearings

United Coke & Chemicals Co. Ltd. have developed a new addition to their range of *Orkot* resin-bonded fabrics for application in the nuclear engineering industry. Known as *Orkot* grade TL, it has undergone extensive radiation exposure and aqueous immersion tests and has been specified for the bearings for the fuel element handling equipment at both Hinkley Point and Sizewell atomic power stations.

The material is tough, hard wearing and has a low coefficient of friction with aqueous lubricants. For dry running conditions, it is available impregnated with graphite or MoS_2. Grade TL is dimensionally stable in the presence of water. **CPE 1742**



Welding tantalum in an atmosphere of the inert gas, argon, at the Royal Dutch/Shell Amsterdam laboratory. Here, metallurgists are studying methods of using tantalum as liners for large pressure vessels where the cost would not be prohibitive **CPE 1743**

Automatic welding

Rockweld Ltd. of Croydon have developed an *Arcos* circomatic automatic girth seam welding equipment for storage tanks, with normal welding speeds of 24 in./min. approximately on a $\frac{1}{4}$-in. plate. The machine weighs 30 cwt. and runs in monorail fashion on the upper edge of each ring of plates. It is able to complete a weld up to $\frac{7}{8}$-in.-thick plate in a single encirclement of the tank. No back-gouging operation is required and the circomatic machine, which can give uninterrupted welding of the full circumference of a tank 120 ft. diam., uses a CO_2 gas-shielded arc and a *Comet* flux-cored wire. **CPE 1744**

Thickener unit

A 30-ft.-diam. thickener unit has been developed and produced by Chemical Equipment Engineering Ltd. of Macclesfield. This is now installed at the new Bedford plant of Texas Instruments Ltd.

It is used on the neutralised stage of the effluent disposal system and is a compact, totally enclosed and oil-lubricated unit. It has machine-cut, involute-helicoidal worm gears which give a much higher tooth loading and silent operation. The rakes can be raised a total of 18 in. and stopped at any intermediate position. An audible warning operates electrically from the loading of the main drive motor and an automatic limit switch prevents overrunning.

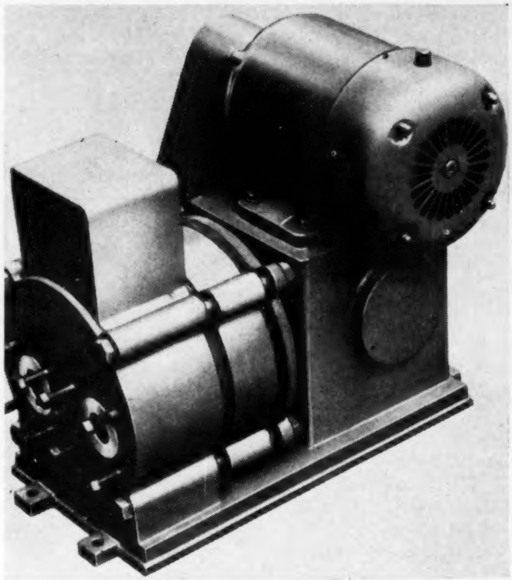
The manufacturers of this unit are now designing a completely automatic

lifting system which is controlled by the main motor loading a simple relay system controlled by the motor amperage. **CPE 1745**

Metal spraying pistol

A model 61 metal spraying pistol has been developed by the Coating Division of F. W. Berk & Co. Ltd. for an hourly throughput of 110 lb. of zinc at a deposition efficiency previously only achieved with low-throughput guns. This throughput enables an area of approximately 450 sq. ft. to be given a 0.004-in.-thick zinc coating, at a cost, including oxygen, propane, powder and labour, of about 4d./sq.ft. The throughput is achieved by splitting the powder stream into four equal small streams and alternating these with gas streams. The gun weighs only 3 lb., and the gas, air and powder hoses all enter at the rear, thus giving good balance. **CPE 1746**

Mitchell Craig are marketing a motor-driven diaphragm pump, type J.2, which is an acid-transfer unit capable of handling a wide range of corrosive and abrasive liquors. It is a short-stroke high-speed unit with built-in air bottle giving even-output flow. The liquid chamber is constructed in a special alumina-loaded ceramic material. The pipe connections can be arranged to take ceramic hose connectors or standard flanged piping. Open-end capacity is 500 g.p.h. and discharge pressure maximum 35 p.s.i. **CPE 1747**



Filter aids

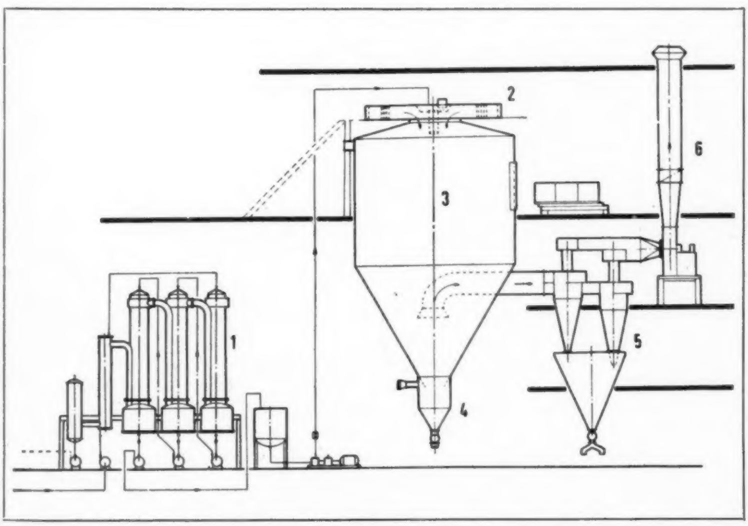
The new *Dicalite Perlite* filter aids, made by F. W. Berk & Co. Ltd., are now available as a result of the opening of a new plant at Ghent. These are of very low density so that at least 25% less can be used compared with conventional materials. They have also proved efficient in filtering liquids containing a higher percentage of dispersed solids, due to the physical characteristics of the particles. They are highly resistant to cracking when applied as a pre-coat on rotary vacuum filters.

Dicalite filter aids, used with pressure or vacuum filters, are said to provide a high degree of water purity, fast flow rates, simplicity of operation and maintenance and minimum space requirements. **CPE 1748**

Chemical and effluent storage tanks

Bristol Aeroplane Plastics Ltd. have developed a reinforced plastics tank incorporating a number of features which greatly increase corrosion resistance and useful life. Originally developed for the U.K.A.E. Research Establishment at Harwell, a number of these tanks are installed to handle radioactive effluent, and the reinforced plastics are made from specially developed resins.

B.A.P.L. are also manufacturing a cylindrical storage tank in resin-impregnated wound glass filaments, and wall thickness and resin quality can be controlled to produce a tank compatible with specific requirements. Tanks can be supplied either with an open top or completely sealed to withstand pressurisation. **CPE 1749**



Diagrammatic layout of spray dryer plant, Luwa process, for free flowing powder showing: 1, evaporators; 2, air inlet and atomising unit; 3, drying chamber; 4, powder cooler and main outlet; 5, cyclone group and powder bunker; 6, exhaust fan and chimney

Spray dryer contract

Steel & Co. Ltd. are to manufacture Luwa spray dryers in the U.K. following negotiations to take over the technical and commercial assets of the spray dryer business of Luwa A.G. of Zurich.

The spray dryer is designed either for independent co-current or counter-current air flow operation and has either a spinning disc or pressure nozzle spraying device. The disc of the former is designed to prevent the build-up of feed liquid on its operating surfaces and rotates at speeds of up to 12,000 r.p.m. The latter operates according to the centrifugal principle and, should the jet become blocked, it can be changed without interrupting the drying process. The spinning disc units have water evaporation capacities ranging from 251 to 300 lb./hr. and diameters of 9 to 23 ft. approximately. Pressure nozzle units cater for capacities of up to 2 to 4 tons/hr. water evaporation. **CPE 1750**

Nuclear Notes

In-core instrumentation

Norway's Institutt for Atomenergi has held its third advanced summer course at the Netherlands-Norwegian reactor school at Kjeller. The subject chosen was 'In-core Instrumentation for Water-cooled Reactors'. The need to measure data accurately was considered of importance for the development of water-cooled reactors.

Besides the practical problems and the effects of radiation on the instruments, the course also considered the measurement of temperature in fuel and canning, hydrodynamic parameters, neutron flux, etc. Lectures were given by scientists from the Institute, supplemented by lecturers from the U.S.A. and U.K.

A panoramic view of the Berkeley nuclear power station. Fuel loading has just begun at Berkeley and Bradwell, Britain's first two commercial nuclear power stations which were designed and constructed for the Central Electricity Generating Board by the Nuclear Power Group and are specifically for the generation of electricity

Fast-reactor programmes reviewed

A review of the fast-reactor programmes of the countries most advanced in this field was given during the closing stages of the seminar on the physics of fast and intermediate reactors, organised by the I.A.E.A. in Vienna. It was hoped that fast-breeder reactors would soon become competitive as a source of cheap nuclear power.

In France the construction of graphite reactors provided ample supplies of plutonium. RAPSODY, a reactor for carrying out experiments on irradiation of fuel elements, was under construction, and a 250-MW thermal reactor would be built towards the end of the present decade to help in designing a true fast neutron power reactor prototype. U.S.S.R. scientists were thinking of designing a reactor of 800,000 kW but, because of large reserves of fossil fuels, the problem of basing the production of energy on nuclear power was not acute. The U.K. programme was envisaging the construction of 1,000-MW commercial fast reactors in the 1970s.

Nuclear energy courses

The European Nuclear Energy Agency of the O.E.E.C. has published a new edition of its 'Catalogue of Courses on Nuclear Energy in O.E.E.C. Countries'. This covers the 1961-62 academic year and gives details of training courses in subjects relating to nuclear energy in some 180 Western European universities, technical high schools and research centres. It contains a list of establishments where courses are given, syllabuses of the main courses and information concerning the principal items of equipment available for training in each establishment.

Nuclear plant costs

Final costs for New England's first atomic electric project will be about \$13 million below the estimates. The reactor for the Yankee Atomic Electric Co. plant is the largest yet designed and developed by Westinghouse Electric Corp.'s atomic power department.

The key to future power costs in New England as they are affected by nuclear electricity will depend upon how steadily the plant can be run and how long the reactor core will last.

Pakistan Nuclear Institute

Plans for the building of a new Pakistan Institute of Nuclear Science and Engineering were recently announced by the Pakistan Atomic Energy Commission.

The nuclear research reactor will be built by American Machine & Foundry Co.'s A.M.F. Atomics Division. The division is also constructing the research reactor facility consisting of the reactor building and associated laboratories, which will be the central part of the Institute. There will be altogether 16 science, engineering, administration and service buildings.

Nuclear power plant

A portable, self-regulating nuclear power plant to generate electricity beneath the surface of the sea or in remote land areas of the world without requiring any operating personnel, is being developed by General Dynamics Corp.

A small package plant, capable of long-term, unattended operation at generating capacities up to 2,000 electrical kW, is under design and development at the corporation's General Atomic Division. It will be equipped with homogeneous fuel and moderator elements of uranium-zirconium hydride, similar to those of the TRIGA research reactors.

Fuel elements

The Babcock & Wilcox Co. has signed a contract with Aerojet General Nucleonics, California, to supply 20 fuel elements for the University of Basle reactor, Switzerland. Enriched to 90% of uranium-235, the plate-type elements are similar to those used in the materials testing reactor in Arco, Idaho. They will be fabricated at the Babcock & Wilcox nuclear facilities plant in Lynchberg, Va., and delivery is scheduled for the autumn of this year.

Designed by Aerojet General Nucleonics, the research reactor will go into operation at the end of 1961, and will be used by the university for student training and research.

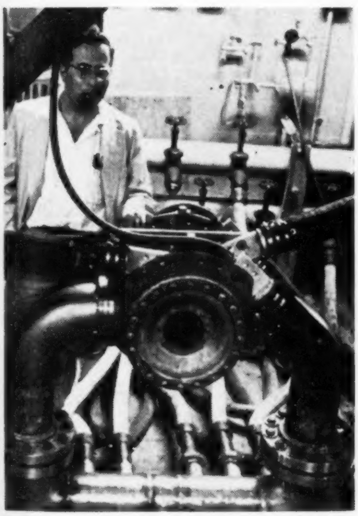
Swedish reactor

Sweden's first commercial nuclear power plant, the combined heat- and power-producing reactor R3/ADAM, will go into operation at the end of next year. Known as the Agesta plant, it is situated on the outskirts of Stockholm. The floor level of the reactor bay is 30 m. below ground and the installation of machinery and other equipment, which started early this year, is now in its final stages.

Designed for a total output of 65 MW, the plant will supply 10 MW in the form of electric power and 55 MW as hot water for space heating of apartments for about 50,000 inhabitants. The R3/ADAM reactor will require 18 tons of uranium dioxide and 70 tons of heavy water to go critical.

Japanese visit

A member of the safety committee of the Japanese Atomic Energy Commission, Prof. H. Uchida, of Tokyo University, recently visited the Atomic Energy Division of G.E.C. Ltd. He toured the nuclear laboratories and saw the company's manufacturing facilities, in particular the turbine and circulator parts for the Tokai nuclear generating station which the British G.E.C. of Japan Ltd. is building for the Japan Atomic Power Co.



Dr. Henry H. Kolm, of the National Magnet Laboratory at the Massachusetts Institute of Technology, with the solenoid magnet in which he produced a continuous magnetic field of 126,000 gauss, believed to be the highest on record. The magnet was developed in a programme initiated and carried out with Lincoln Laboratory support under Air Force sponsorship and was engineered and built by High Voltage Engineering Corp.

Orders and Contracts

Plant extension

A contract for the engineering of a plant, the finished cost of which will be approximately £250,000, for the Dyestuffs Division of I.C.I. Ltd., has been awarded to John Thompson (Wolverhampton) Ltd. The contract comprises extensions to an existing intermediate plant and includes vessels ranging from 50 to 2,000 gal. capacity, suitably lined wherever required. The plant is scheduled for starting up in 18 months.

A Chemical Plant Design and Construction Engineering Division has been established by John Thompson (Wolverhampton) Ltd. at the company's main works at Ettingshall, which will be able to offer facilities for effecting the complete plant contract, including mechanical, electrical and civil work.

Dust research laboratory

Keith Blackman Ltd., manufacturers of *Tornado* fan engineering and industrial gas equipment, have placed a further contract with Hale Construction Co. Ltd. for a new heavy fabrication shop and dust research laboratory. The contract is valued at £45,000 and is the second to be placed with Hale Construction Co. Ltd. as part of Blackman Ltd.'s expansion programme. The first contract, which is nearing completion, was valued at £25,000.

Distribution facilities

Petrofine (G.B.) Ltd. have awarded a package contract to William Press & Son Ltd. for the design, supply, erection and commissioning of distribution facilities at the Sunderland installation of Petrofina and at the corporation quay, Sunderland. The first part of the contract is valued at £234,000.

Beryllium research contract

A research contract for £2,500 has been awarded to the Australian Mineral Development Laboratories by the A.E.C. for the study of methods of recovering beryllia from the naturally occurring mineral beryl.

In 1957, the Commission instituted a programme of buying and stockpiling beryl produced in Australia. This was in the form of crystals and the new research contract should throw light on the best means of reducing this material to the forms needed.

Pulp mill

Electrical controls for a pulp mill at Stalinvaron in Hungary are being manufactured by Brookhirst Igranic, a company in the Metal Industries Group. The mill will produce bleached sulphate pulp from straw.

The order, which has been placed by Lyddon & Co., London, is valued at £75,000. It includes the provision of 15 motor control centres, incorporating between 250 and 300 starters, mainly of the direct-on-line type, with a separate push-button station for each motor.

Industrial drying equipment

John Dalglish & Sons Ltd. have signed a contract with the U.S.S.R. for the supply of machinery worth approximately £1.5 million. It will consist of two complete plants for the filtration, drying, wrapping and packing of butyl synthetic rubber. The equipment will be delivered to Russia during the latter part of 1962. This follows the award in March 1961 of two smaller contracts for butyl synthetic rubber, value approximately £200,000, for delivery to Russia by the end of this year.

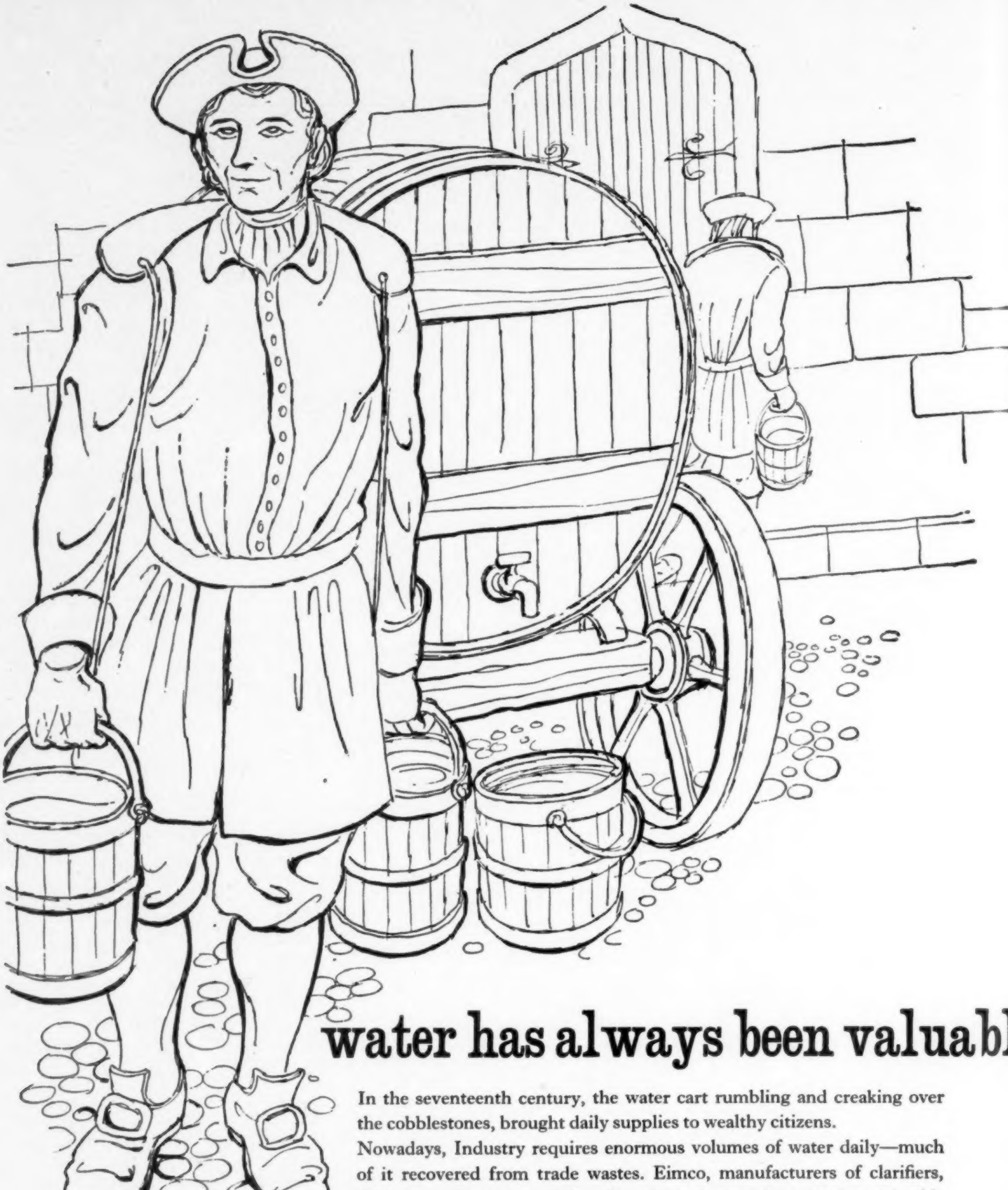
Continuous galvanising plant

The Head Wrightson Machine Co. Ltd. have received an order from the Steel Co. of Wales for an Armco *Sendzimir* continuous hot-dip galvanising plant to be installed at Port Talbot. The Head Wrightson Machine Co. are the main contractors for the plant and will be responsible for the design and engineering. The furnace for annealing and surface preparation will be built by A.E.I.-Birlec.

Ore-handling installation

The new sinter plant and ore-handling installation at Lysaght's Scunthorpe works have been designed to handle 600 tons/hr. of run-of-mine ore. The main contractor for this project was Head Wrightson Iron & Steel Works Engineering Ltd., who placed an order for ore-handling plant with G.E.C. Ltd. The total value of the G.E.C. contracts was approximately £700,000 and included a 60-ton side-discharge wagon tippler, crushers, conveyors, screens and feeders.

Three types of ore are handled in the new plant, namely Lincolnshire, Northamptonshire and French.



New Books

The Proceedings of the International Symposium on Distillation. Published by The Institution of Chemical Engineers, London. 1961. Pp. 281. £4 (£3 to members of sponsoring organisations).

This volume contains the proceedings of the 24th meeting of the European Federation of Chemical Engineering, which was organised jointly by the Institution of Chemical Engineers and the Chemical Engineering Group of the Society of Chemical Industry. It contains 28 papers, more than half of these being by British authors and the remainder from European authors, with the exception of a solitary paper from the U.S.A.

The papers are classified into six groups corresponding to the actual sessions held at the conference: heat and mass transfer, 1 and 2; vapour-liquid equilibria; performance of packed columns; and performance of tray and other columns, 1 and 2. The discussion of the papers presented in each session is given at the end of the relevant group of papers.

The first session of the symposium opened with a thought-stimulating paper on the effects of heat transfer and interfacial tension on plate efficiencies. Further evidence is given to support the fact that heat transfer (interstage) plays a much greater part in some distillation processes than hitherto suspected. The much-neglected topic of steam distillation is also dealt with in this group of papers.

The complex phenomenon of foaming and frothing is the subject of part of the second group devoted to mass-transfer effects. Elegant methods, *i.e.* optical reflectivity and gamma-ray transmission, are presented for measuring the properties of foams and providing a better understanding of their contribution to the efficiency of fractionating devices.

Vapour - liquid equilibria studies form the major part of the third session and especially welcome are the papers covering non-ideality and activity coefficients. The most outstanding paper of the symposium is to be found in this group being devoted to a thermodynamic interpretation of vapour-liquid equilibria. The fact that only two papers are devoted to the very important topic of experimental determination is rather surprising.

The fourth group is devoted to the performance of packed columns and contains the two Russian papers, both having a refreshing outlook. The first is confined to a study of film distillation in a variety of devices and the other, from the Mendeleef Institute for Chemical Technology, examines critically the mass-transfer processes occurring in packed columns.

The remaining sections of the proceedings contain papers on the performance of bubblecaps, perforated plates, jet trays and turbogrids. In particular, two papers give a comparison of fractionating devices and, not being entirely complementary, stimulate a rewarding discussion. The newer devices, *i.e.* the rotary disc column and the Luwa rectifier, also receive attention. By way of interest, a new chemical engineering factor hitherto undefined in the classical texts emerges in the discussion. This is named the 'bikini' factor (*loc cit.* p. 216).

The overall impact of this volume is that it deals mainly with the problems underlying the mechanism of the distillation process. It is certainly one of the most stimulating symposia to have been published on a chemical engineering topic, and provides considerable food for thought. Further, it is a most up-to-date statement of our knowledge of distillation and serves to emphasise the need for a critical and authoritative text on the subject. Those who consider the symposium too theoretical are recommended to read the concluding remarks of the second session's chairman, Prof. Warren K. Lewis, which are published together with Lord Fleck's opening remarks in *The Chemical Engineer*, June 1960.

The volume can be recommended unreservedly to all those who have an interest in distillation and the price is reasonable in view of the high standard of the contents and printing. The editor and organisers are to be warmly congratulated.

S. D. HOLDSWORTH

Process Chemistry: Progress in Nuclear Energy, Series 3, Vol. 3. Editors: F. R. Bruce, J. M. Fletcher and H. H. Hyman. Pergamon Press, 1961.

In this book the editors have selected 27 from the 200 papers presented to the second Geneva Conference on the Peaceful Uses of Atomic Energy to describe important developments in the chemistry and technology of reactor fuel processing.

The first two chapters are concerned with the recovery of uranium ores, subsequent refining and the production of feed materials. Recent developments in Sweden, Canada and the United States are discussed and a paper by Thayer describes the latest American plant at Weldon Spring, Missouri. It is apparent that developments in uranium processing are now concerned primarily with improvements in technology.

Chapter 3 describes aqueous processes for the treatment of irradiated uranium fuels. These are all aimed at the separation of uranium, plutonium and fission products. Outstanding papers are those by Howells *et al.*, who describe the complete Windscale *Butex* process, including descriptions of the underlying chemistry of the process, flowsheets and control systems, and by Cooper and Walling, who provide a masterly account of American experience in the processing of irradiated natural and enriched uranium fuels.

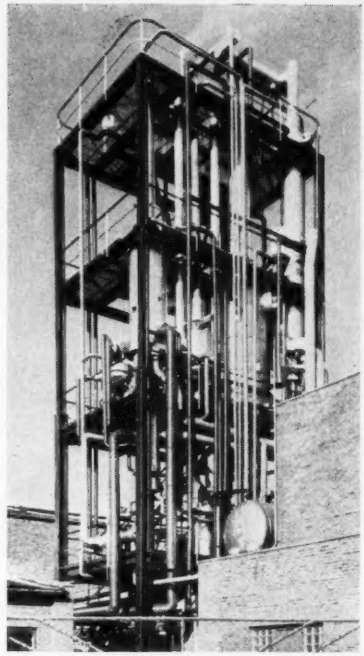
Chapter 4 covers non-aqueous processing and all the papers are based on American developments.

The section on waste disposal discusses two specific topics and not the subject as a whole. Loeding *et al.* describe a fluidised-bed conversion of liquid to solid waste which is of importance in dealing with liquids containing high concentrations of aluminium, and Blasewitz and Schmidt consider some of the methods used in the American factories for treatment of radioactive waste gases. The concluding chapter by Bruce provides an excellent summary of all the Geneva papers relevant to the field.

The editors have made a good choice of papers and the general presentation, including adequate bibliographies, makes this a valuable reference book. The main criticism, which must be made about so many books now, is that three years have elapsed since the original papers were written, and so more recent developments have not been included.

G. R. HALL

CPE Company News



A fatty acid distillation and fractionation plant with a capacity of 1 t/h at the Koln-Niehl works of Wilhelm Schmidding Ltd., makers of apparatus and machinery in Germany

Company reorganisation

Whessoe Ltd., tank and plant builders for the oil, chemical, gas and, more recently, nuclear power industries, have widened their activities during the past few years. Major reorganisation of the company is being carried out in order to deal more efficiently with the problems created by this growth.

It is now re-formed into five divisions, three of which are operating divisions and the other two service divisions. The former includes heavy equipment, light products and engineering services, and the latter, research and development, and finance and administration.

The Light Products Division is building a factory in the Calais area and a subsidiary company is being formed in Nigeria.

Precipitators

A new division to handle the design, construction and installation of electrical and mechanical precipitators is announced by Joy-Sullivan Ltd. This move is the result of the merging, in 1959, of Western Precipitation Corp. with Joy Manufacturing Co., parent company of Joy-Sullivan Ltd.

Chiefly concerned with equipment for the control and recovery of particulate matter in industrial gases, the range of plant to be offered will include precipitators, filters, scrubbers and certain processing and heating equipment.

Progress on the £3m. expansion scheme of Laporte Titanium Ltd. at Stallingborough, Lincs. The extensions will increase annual production of titanium oxide from 30,000 tons to 50,000 tons by 1962

Synthetic fibre plant

The construction of I.C.I.'s new synthetic fibre plant at Kilroot, Northern Ireland, is proceeding to programme.

The plant is being built in a number of phases, and activities at the moment involve the building of a number of service buildings together with the initial production units.

It is hoped that the first stage of construction will be completed towards the end of 1962, when initial production will then commence.

Plastic film company

I.C.I. Ltd. and E. S. & A. Robinson (Holdings) Ltd. are entering into an association to develop the uses of plastic films in the packaging industry.

I.C.I. are subscribing for a minority interest in a new Robinson subsidiary to be called Robinson Plastic Films Ltd. which, together with other Robinson subsidiaries, will manufacture a wide range of plastic film products for the packaging industry. Robinsons are acquiring a minority interest in British Visqueen Ltd., which is an I.C.I. subsidiary undertaking the manufacture and conversion of polyethylene and other plastic films. It is believed that this combination will lead to the widest development and most efficient production of plastic films for all packaging uses.

Computer control for plant

Monsanto Chemical Co. in America has purchased four digital computers for on-line control computation in its multi-million-dollar hydrocarbon raw materials plant currently under construction at Texas. The computers are being supplied by Honeywell Controls Ltd., who are also providing a full complement of electronic instruments.

The Texas plant, to be placed in operation late in 1962, is a move by Monsanto toward self-sufficiency in hydrocarbon raw material for its chemical processes. It will include an ethylene unit with annual capacity exceeding 250,000 tons. In addition, the plant will produce benzene, naphthalene, propylene, cumene, phenol, acetone, ethyl benzene and other hydrocarbons.

New division

In order to extend their services in the chemical, nuclear and petroleum fields, Uddeholm Ltd. have inaugurated a new division. Known as the Chemical and Nuclear Plant Division, it will be concerned with the design, fabrication and sales in stainless and clad steel of all types of tanks, pressure vessels, heat exchangers, fractionating columns, etc.

Benzene plant

A Houdry *Detol* plant with a nominal design capacity of 17,000,000 gal. p.a. of benzene has gone on stream at the Crown Central Petroleum Corp's refinery, Texas. This new unit is producing the expected high yields of improved nitration-grade benzene, by the hydrodealkylation of toluene.

The *Detol* process produces benezene by dealklylating toluene, xylenes, mixtures of the two, or alkyl benzene concentrates, all at close to theoretical yields. If the charge stock contains minor quantities of non-aromatics, such as paraffins or olefins, they are converted to light hydrocarbons.

World News

IRAN

Exploration well

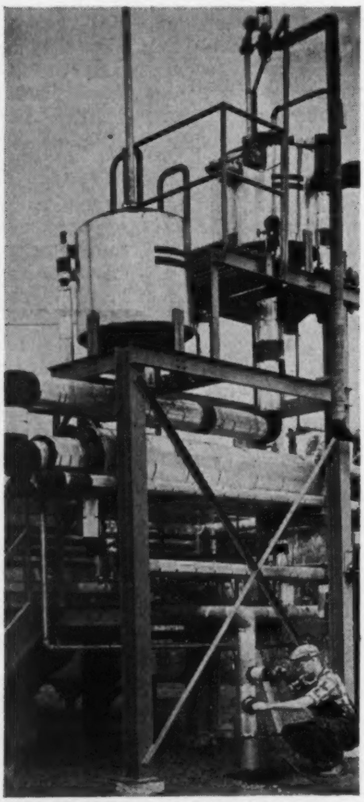
The Iranian Oil Exploration & Producing Co. has suspended the drilling of its exploration well, Bibi Hakimeh No. 1. The well yielded about 3,500 bbl./day of oil after special treatment, but a prolonged production test would be required to evaluate the realistic potential of the well. Facilities for this are being installed, and there is to be further drilling in the area in the near future to establish whether a commercial oil field can be developed.

YUGOSLAVIA

Synthesis gas production unit

Société Bèlge de l'Azote et des Produits Chimiques du Marly (S.B.A.), Liège, and D. Bonaldi & Co. SpA., Italy, have concluded an agreement in order to supply the Yugoslav firm Proizvodnja Nafte with a plant for the production, from natural gas, of gas suitable for a methanol production unit.

The plant is designed by the Engineering Division of S.B.A. and operates a technique, called 'S.B.A.-H.T. process', owned in common by S.B.A. and the Topsøe Co., Copenhagen. The S.B.A.-H.T. process enables the production of synthesis gas for ammonia and methanol, by cracking of various hydrocarbons.



The acid stabilisation unit of a PETN explosives plant recently opened at Beloiel, Canada, by the Explosives Division of Canadian Industries Ltd.

FRANCE

Isocyanates

Etablissements Kuhlmann of Paris and E.I. du Pont de Nemours & Co. Inc., U.S.A., will form a new French company to manufacture and sell isocyanates. Each will own 50% of the stock of the new company, to be called Dekachimie, and capitalisation will amount to 30 million new French francs.

Dekachimie will build a plant near Lille at Etablissements Kuhlmann's existing La Madeleine plant. Construction will begin early next year and the plant will be completed in 1963. Meanwhile, isocyanates from the United States will continue being sold in the European market by the new company.

Synthetic rubber production

A synthetic rubber plant which was commissioned by Firestone (France) S.A. (subsidiary of the U.S. Firestone Tire & Rubber Co.) will shortly commence production of SB-R rubber and latex. The capacity will be 20,000 tons p.a.

Raw material will be supplied from the nearby Esso-Standard refinery at Port Jérome.

UNITED STATES

Computer control

The first fully automated plant of Allied Chemical Corp. will be operated by the Nitrogen Division at Ironton, Ohio. The division's ammonia plant will be placed under automatic control of a Thompson Ramo Wooldridge RW-300 digital control computer which is expected to be in operation before the end of the year.

The computer will control the ammonia process by reading instruments and performing programmed calculations. It will then automatically adjust process controls to achieve optimum operating conditions.

Process control

Tracerlab Inc. will furnish automatic process control units to the Armstrong Rubber Co.'s West Haven, Natchez and Hanford tyre plants. These will be used for all calender control functions in the application of rubber to the tyre cord, assuring a high standard of dimensional uniformity regardless of the width of the tyre fabric.

ITALY

Carbon black production

The carbon black plant of San Martino a Trecate (Novara), opened recently, is now in full production. The plant is owned by Columbian Continental Europa, a joint venture of Columbian Carbon, New York, and Continental Carbon of Houston. The highly automated plant produces ISAF, HAF and FEF. Italy is now one of Europe's largest exporters of carbon black.

BELGIUM

Pure benzene

Union Chimique Bèlge S.A. has recently constructed a new plant in Havré-ville for production of superfine benzene, toluene and xylene from coal tar. This plant has a capacity of 3,000 tons p.a. A substantial part of this benzene will be used for production of maleic anhydride. It is planned to build the maleic anhydride plant on the same site. Until recently Union Chimique Bèlge was the only Belgium maleic anhydride producer, but now Société Chimique de Selzaete S.A. has commissioned a maleic anhydride plant which should be completed by 1962.

£ s d

CHEMICAL PLANT COSTS

Cost indices for the month of August 1961 are as follows:

Plant Construction Index: 185.8

Equipment Cost Index: 174.9

(June 1949 = 100)

£ s d